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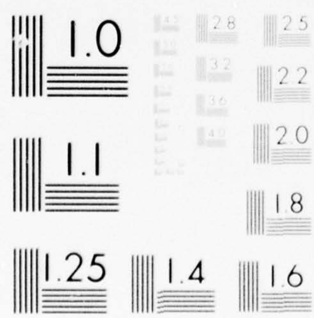

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Wright-Patterson Air Force Base, Ohio

SIMULATION OF AN AIR TRAFFIC
CONTROL TERMINAL AREA

James M. Gibbar, Captain, USAF
Gary E. Lorenz, Captain, USAF

LSSR 15-77A

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1. REPORT NUMBER: LSSR-15-77A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): SIMULATION OF AN AIR TRAFFIC CONTROL TERMINAL AREA.		5. TYPE OF REPORT & PERIOD COVERED: Master's Thesis.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): James M. Gibbar, Captain, USAF; Gary E. Lorenz, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Graduate Education Division, School of Systems and Logistics, Air Force Institute of Technology, WPAFB, OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Department of Research and Administrative Management (LSGR), AFIT/LSGR, WPAFB, OH 45433		12. REPORT DATE: June 1977
		13. NUMBER OF PAGES: 175
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

012250

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE AFR 190-17.

JERRAL F. GUESS, CAPT, USAF
Director of Information

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

1. Air Traffic Control 2. Simulation Model
3. Development Methodology 4. Experimentation
5. Data Collection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Eugene E. Jones, Lt Col, USAF

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The air traffic controller is at the apex of a complex information system. High volume air traffic often precludes thorough data analysis by the controller and reduces his ability to plan for optimum traffic flow. Simulation offers a means to evaluate changes in air traffic control procedures or facilities. Such changes could assit the controller in maintaining optimum traffic flow. This research involved the development of a computer-simulation model of an approach control area. Experiments were conducted on the model to test the effect of various changes in procedures and facilities. The results of the experiments were inconclusive.

LSSR 15-77A

SIMULATION OF AN AIR TRAFFIC

CONTROL TERMINAL AREA

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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June 1977

This thesis, written by

Captain James M. Gibbar

and

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has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 15 June 1977

Eugene E. Jones

COMMITTEE CHAIRMAN

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cheerful attitude and continuous support of our wives, Mary and Linda.

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Chapter 1

INTRODUCTION

Air Traffic Control (ATC) is a broad concept designed to provide information and assistance to insure the safe, orderly flow of aircraft. It is a concept rooted in a complex system of flight rules, regulations, and procedures which becomes tangible in the form of a multitude of facilities using varying degrees of communications, radar and computer technology. Positive ATC, however, is achieved through the interaction of people; in particular, through the interaction of pilots and air traffic controllers.

To accomplish his job, the air traffic controller is placed at the apex of an information system. His information sources are many: radio communications, radar presentations, flight plans, flight progress strips, and telephone communications. The information he receives describes the dynamic air traffic environment at any given instant in terms of numbers, locations, directions, velocities and altitudes of aircraft. The controller's responsibilities are to continuously assess the information, to recognize potential conflicts, and to formulate and implement corrective action in a timely manner. As the density of air traffic increases, a corresponding increase in information input to the controller and in the probability of traffic conflict occurs.

Simultaneously, the time available for the controller to evaluate data, to recognize potential conflicts, and to formulate corrective action decreases.

Safety dictates that he concentrate his attention on the resolution of potential conflict. To achieve this end, he will take appropriate corrective action. In the context of conflict resolution, a controller's corrective action can be characterized as preventative in nature and may impose an economic penalty in terms of the costs incurred by the various delaying techniques employed to preclude conflict.

Economic considerations are less important than safety considerations, but could both be optimally dealt with simultaneously, regardless of the air traffic situation? In answering this question two important elements must be considered: The amount of time the controller has for data analysis, and the amount of information available to develop a plan for optimum traffic flow.

Statement of the Problem

The problem is twofold. One, the air traffic controller does not always have sufficient time to develop a plan to maximize both safety and economy; and two, he does not have adequate information to formulate such a plan.

Improvements in the design of the air route system could provide the controller with additional time and

increase his effectiveness by simplifying and streamlining the flow of traffic. The greatest potential for design improvements lies in the terminal, or approach control area (ACA). It is within the ACA that arrival routes, after having separated from the enroute network of air routes, converge on the destination airport and that departure routes diverge from the airport to link up with the enroute structure. In the ACA, arrival and departure routes are integrated into a single network of flight paths normally characterized by progressive altitude restrictions. Aircraft flight separation requirements, both vertical and horizontal, are driving forces in designing the ACA and in developing procedures to handle air traffic in the ACA.

Significant changes to the ACA cannot be implemented on an experimental basis, however, without running the risk of disrupting operations. Furthermore, changes can be quite costly and time consuming (17:1), depending upon the extent of physical re-design and upon the amount of coordination among air traffic agencies required by the Federal Aviation Administration (FAA).

An alternative to actually experimenting with an ACA in seeking design improvements is to use computer assisted simulation. Tuan defines a computer-simulation model as

> ... a procedural-logical-mathematical representation of a real-world system programmed for digital computers within which experiments can be conducted over specific periods of time [17:1].

Computer-simulation is an ideal instrument to experiment with a variety of changes to the ACA, and to evaluate their effect, without creating actual traffic disruption and without incurring excessive costs. Potential changes to the ACA that can be explored through simulation include: (1) Changes in the routing of flight paths; (2) Changes in the allocation of controlled airspace; (3) Changes in the location of flight facilities; (4) Changes in procedures and regulations to handle traffic; and (5) Changes in the decision rules used by controllers to sequence air traffic (17:2). Those changes that prove to be of benefit through simulation experiments could then be considered for actual implementation in the ACA.

Besides assisting in the evaluation of changes in the ACA which provide the controller more time, simulation could be used to provide the controller additional information. The effect of various controller actions on simulated traffic, representative of a controller's real traffic at any given time, could be evaluated on a near real-time basis (17:5). In this respect the controller would have assistance in planning since he could evaluate a course of action prior to its implementation. The planning assistance, hopefully, would result in an optimal flow of air traffic that not only considers flight safety but ecomony as well.

Literature Review

The application of computer technology to the terminal ATC environment is not a new concept. A report by the Mitre Corporation presented four articles (15:9-14) which summarized the present state of automation of terminal and enroute ATC facilities. Technical features of the Automated Radar Terminal System (ARTS) were described in some detail. The ARTS provides alphanumeric data blocks (containing aircraft identity, altitude, and ground speed) which are superimposed on the controllers radar display (15:1). The development of the ARTS has provided the controller with an improved picture of the existing traffic situation, and allows him to monitor aircraft flight progress to insure compliance with control instructions.

The Mitre report also discussed the Radar Data Processing (RDP) System, Conflict Alert, and Intermittent Positive Control, all of which have application to the terminal area. RDP is directed towards improvement of the accuracy and reliability of radar surveillance of aircraft. Conflict Alert and Intermittent Positive Control are both being developed to prevent midair collisions in congested areas (15:19-26). The procedure involves the continuous surveillance of a block of airspace projected in front of each aircraft. If the projected airspace of two or more aircraft intersect, the computer provides an alert signal to the controller.

The articles mentioned above were concerned with functionally oriented technological capabilities. This technology provides the basic building blocks onto which can be added control aiding functions. Holland and Garceau presented a summary of selected efforts in the area of control aiding functions (7:3-1 to 3-123). These efforts represent an evolutionary development which has culminated in recent efforts to completely automate the sequencing and spacing of aircraft. The more important of these projects are: Final Approach Spacing for ARTS (FASA), and Computer Aided Approach System (CAAS).

The FASA project involved the preliminary sequencing of aircraft based on predicted arrival times at the runway. The sequence is modified, if necessary, prior to the Final Approach Fix (FAF)* and from that point the sequence is firm (7:3-94 to 3-109). Although the method employed in this project appears to have potential, a field test was inconclusive because of difficulties in implementation.

The CAAS project attempted to achieve final approach spacing by using a computer to specify departure times from navigational fixes outside the ACA. Departure times were then "made good" by enroute or transition controllers. A field test indicated the CAAS system provided more consistent and accurate landing intervals than the manual

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*See Chapter 2, Definitions.

control system. Other potential benefits were not conclusively identified due to constraints imposed by the test environment. In addition, the system was not favorably received by the controllers since it caused an increase in workload (7:3-109 to 3-123).

The use of simulation as a means to evaluate alternative control methods was presented by Gabrielli. In his study, Gabrielli experimented with approach geometries (geometric arrangements of flight paths leading to a runway). Two approach geometries were compared using the statistical output from a computer simulation. The comparison was used to support his recommendation of one geometry over the other (6:1-21).

A similar method was used by Mohleji and Horowitz in their analysis of Denver's Stapleton Airport. Their study compared various approach geometry configurations via computer simulation and recommended an optimal geometry for use in conjunction with the ARTS system. The recommendation was not adopted, however, because of the heavy reliance on visual separation of aircraft in the Stapleton ACA. Visual separation allows reduce intervals between aircraft and last minute pilot initiated corrections near final approach. Consequently, the automated control system could not exceed the effectiveness of the manual control system by a significant margin (10:1-1 to 5-4; 9:5-1 to 5-8).

The FASA, CAAS, and approach geometry studies provide evidence that simulation can be a useful tool in the analysis of traffic flow. A synthesis of the approaches taken in these studies has provided the basis for this research. In addition the Holland and Garceau report provides a listing of control tools that can be incorporated into the development of an ATC simulation model (7:2-1 to 2-18).

Justification

In the summer of 1968, the Department of Transportation Air Traffic Control Advisory Committee was formed ". . . for the purpose of recommending an air traffic control (ATC) system for the 1980's and beyond [19:3]." The committee's technical staff was composed of approximately 150 people drawn from all segments of the aviation industry and

> . . . concentrated on control of aircraft through the airspace, from takeoff to landing. Emphasis was placed on the denser portions of the airspace where the danger of midair collisions and the need for efficient use of scarce resources (principally runways and terminal airspace) make sophisticated ATC mandatory if safety is to be assured without sacrifice of capacity and without unacceptable delays or interference with freedom of flight [19:3].

The report of the committee pointed out air traffic was experiencing severe problems and noted the crisis at a few high volume airports was due to the failure of airport capacity and of air traffic control capacity to keep pace

with the growth of the aviation industry. The committee further noted the demand for ATC service was estimated to almost triple by 1980 and to triple again by 1995 (19:5).

Simulation provides a logical and economic means to experimentally test new concepts designed to cope with increasing demand for ATC services. In addition it is possible to test ATC designs for efficiency at present levels of traffic and at the levels predicted to occur in 1980 or 1995.

There is additional justification for this research in the potential economy resulting from improved traffic handling. Simulation-based analysis of the air traffic controller's environment provides a means to reduce air transportation costs. The inherent assumption in this approach is that in any given air traffic situation there exists an optimal method to handle the traffic which will keep in-flight time, flight distance, and fuel consumption at minimum levels. In addition, the efficient handling of aircraft will effectively reduce the workload imposed on the controller. These savings, in particular the reduction of fuel consumption, are of direct interest to the Department of Defense (1:39-41; 20:7-10).

Objective

The objective of this research was to apply computer simulation technology to a specific military ACA as

a means to explore and to evaluate potential improvements in ACA design or ATC procedures. This objective was to be pursued in three sequential phases.

The first phase called for the development of a simulation model. The model, once validated, would then become the basic tool to be used in each of the remaining three phases. In order to be a useful tool, the model had to duplicate an actual ACA as close as possible in both the physical design features of the ACA and in the flow of air traffic within the ACA. Once the model was constructed and validated, phase two could commence.

Phase two required that the validated model be used in an experimentation process wherein potential changes in design or procedure could be tested. Experimentation would involve altering the validated model, to reflect potential improvements, and comparing the output of the altered model against that of the validated model.

Following experimentation, phase three dictated the integration of the validated model with a computer algorithm to identify potential air traffic congestion or conflict. The idea underlying phase three was to use simulation to evaluate various controller actions that could be implemented to preclude impending congestion or conflict. Such an evaluation procedure could be used to test the feasibility of providing the controller with near real-time information to assist him in conflict resolution.

Research Questions

This research sought the answer to the following four questions: (1) Can the variables comprising the military ATC environment be adequately represented by a computer model? (2) Can changes in the terminal environment be effectively evaluated by the simulation model? (3) Can the model be used to predict future congestion or conflict? (4) Can the model be used to compare available solutions to a predicted conflict situation and select a course of action to resolve the conflict?

Chapter 2

BACKGROUND

Thie research specifically focuses on a single ATC facility, the Dayton Approach Control, at Wright-Patterson AFB, Ohio. A computer simulation model was developed to represent the air traffic environment within the Dayton ACA. Simulated air traffic, having the same frequency, volume and mixture characteristics as actual air traffic in the Dayton ACA, is generated by the model and flows through the simulation. The simulation model considers the interaction of all air traffic but is limited to the sequencing of aircraft to and from the runway at Wright-Patterson AFB; the model has not been expanded to include other airfields located within the Dayton ACA.

The Dayton ACA

The geographical (horizontal) boundaries of the Dayton ACA are depicted in Figure 1. Within these boundaries, Dayton Approach Control has jurisdiction over the airspace from the surface up to 9,000 feet except in the vicinity of the Rosewood and the Richmond navigation facilities (i.e. VORTACs). Over the Rosewood and the Richmond VORTACs, Dayton Approach Control's airspace extends from the surface upward to 5,000 feet and to 4,000 feet, respectively.

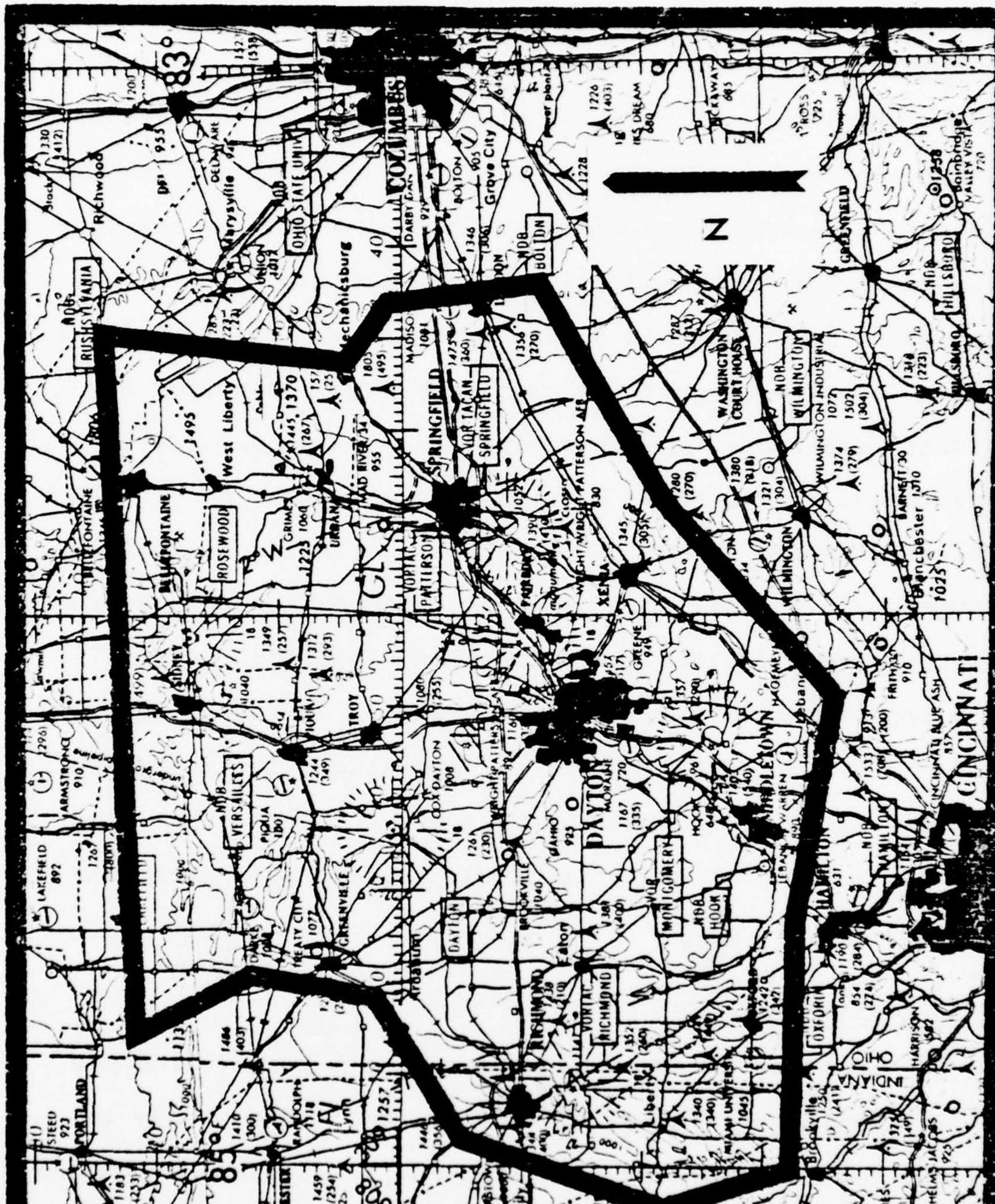

Figure 1. Dayton Approach Control

There are 12 airports located in the Dayton ACA. The two major airports are Wright-Patterson AFB and James M. Cox--Dayton Municipal Airport. Eleven low altitude airways penetrate the Dayton ACA and six electronic navigational aids, used to define airways and instrument approaches, are contained within the boundaries of the Dayton ACA. Aircraft navigate within the ACA by use of the navigational aids, by radar vectors assigned by Dayton Approach Control or by visual references. Aircraft operate in accordance with Instrument Flight Rules (IFR) or Visual Flight Rules (VFR). The air traffic in the Dayton ACA is a mixture of military, commercial, and civilian aircraft. The Dayton ACA recorded approximately 237,500 air operations* in Fiscal Year 1975, and approximately 227,300 air operations in Fiscal Year 1976 (3). The percentage of air operations in the Dayton ACA generated by Wright-Patterson AFB has been calculated by the statistical analysis of air traffic data (see Data Collection).

Wright-Patterson AFB

Wright-Patterson AFB has a single runway oriented to a magnetic bearing of 050/230 Degrees. The runway is 12,600 feet long by 300 feet wide and is adequate to handle

*The phrase "Air Operation" includes such activities as: takeoff, landing, through-flight, execution of an instrument approach procedure, and execution of a missed approach procedure. For a more technical definition, see FAA Regulation 7210.3, pages 179-181.

the largest aircraft. Ten approach procedures are available for navigation to the runway. These include both low and high altitude non-precision instrument approach procedures, Approach Surveillance Radar (ASR). Precision Approach Radar (PAR), and Instrument Landing System (ILS) approaches. Figure 2 is a diagram of the air field at Wright-Patterson AFB.

Computer Language

The simulation programming language used in the development of the simulation model of the Dayton ACA is the General Purpose Simulator System (GPSS). GPSS is both a computer language and a computer program. As a language it provides the capability to describe a system with a well defined vocabulary and grammar. With GPSS a discrete-event simulation computer model of a system can be built to reproduce the dynamic behavior of the system over time (14: vii). As a computer program, GPSS interprets the simulation model of the system described in the GPSS language, thereby making it possible to conduct experiments with the simulation model on a computer. The GPSS program schedules each event for each traffic element in the system, to occur in future simulated time by reference to a self-contained simulation clock (8:2-1). It also causes the events to occur in the proper time-ordered sequence and provides a means of assigning relative priorities to be used in resolving time conflicts.

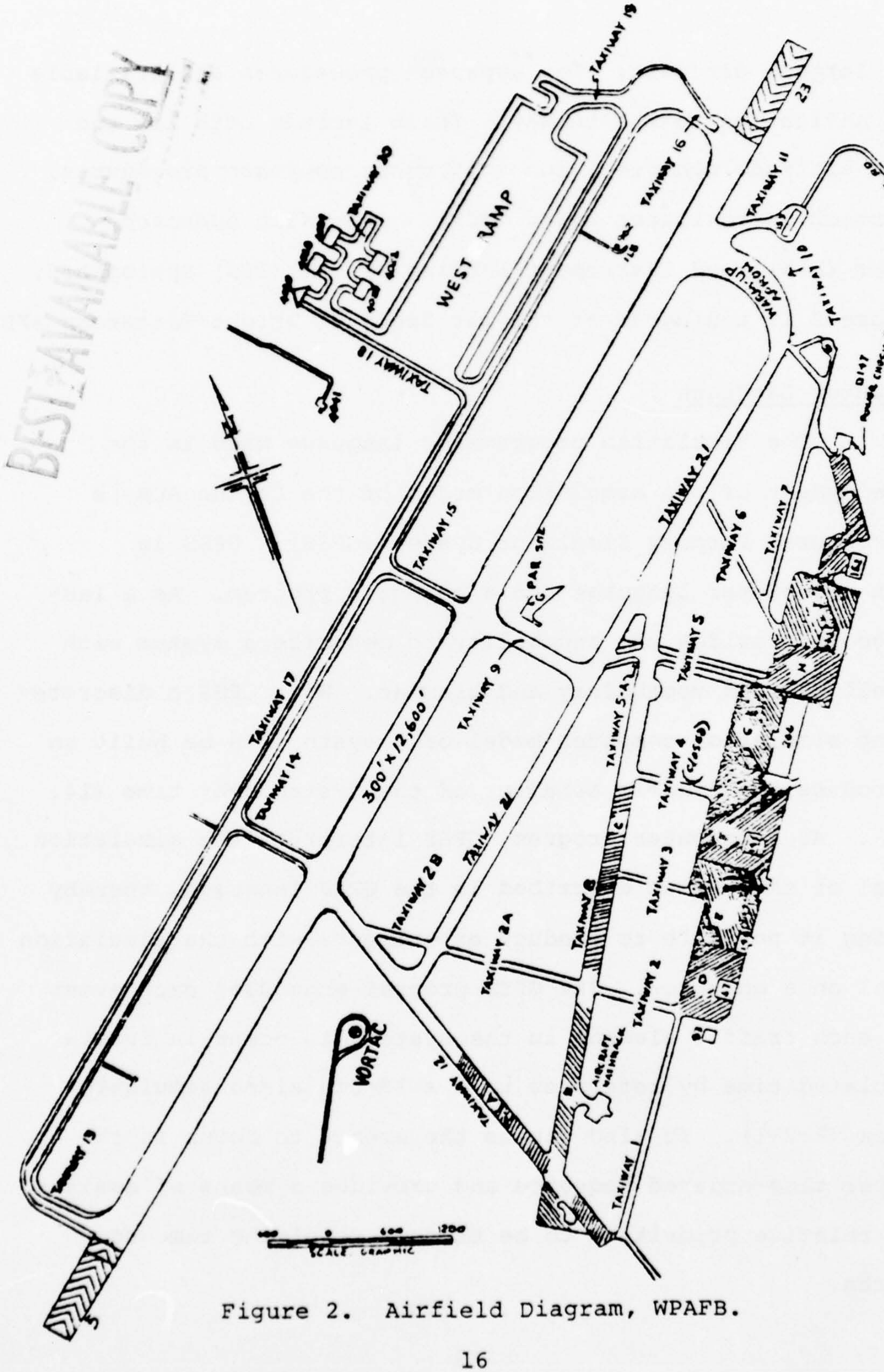

Figure 2. Airfield Diagram, WPAFB.

Definitions

The following list of definitions is provided for clarification of terms used in this paper.

Airspeed: The velocity of an aircraft through the air mass. In the context of this paper, airspeed is considered to be the same as groundspeed; that is, the aircraft's speed over the ground. (1) Cruise Airspeed - the airspeed maintained in level flight at an enroute altitude. (2) Maneuvering Airspeed - the airspeed used within the Approach Control Area to maneuver the aircraft from an Arrival Fix to the Final Approach Fix. (3) Final Approach Airspeed - the airspeed used during final descent for landing.

Alternate Vectoring Route (AVR): Any route other than a Standard Vectoring Route.

Approach Control Area (ACA): The airspace under the control of personnel at the Radar Approach Control Facility (including tower controllers). The horizontal (geographic) and vertical (altitude) boundaries for the Dayton ACA are presented at the beginning of this chapter.

Approach Geometry: A designated route for vectoring aircraft from an Arrival Fix to a Final Approach Fix.

Arrival Fix (AF): A point in close proximity to the perimeter of the Approach Control Area. Aircraft inbound to the

Dayton ACA are transitioned from the enroute structure to the AFs. During the transitioning process, control of an aircraft is transferred from the enroute controller to the Approach controller.

Conflict: A situation in which two or more aircraft will arrive at the same point at the same time without required vertical or horizontal separation.

Congestion: A situation wherein the rate of arriving aircraft is such that one or more aircraft must be delayed in order to prevent conflict.

Final Approach Fix (FAF): The point from which an aircraft initiates its final descent for landing. An aircraft is maneuvered either by a Standard Vectoring Route or an Instrument Approach Procedure so as to arrive at the FAF at the required altitude, airspeed, and heading.

Flight Information Publications (FLIP): A variety of publications for use by pilots and navigators in planning and executing a flight. FLIP is provided by the Department of Defense (DOD) primarily for use by military aircrews. An analogous set of publications is provided by the Federal Aviation Administration (FAA) for use by civilian pilots and navigators.

Flow Control: A process of controlling aircraft in order to meet a scheduled sequence. Flow control may involve delaying or accelerating particular aircraft in a given traffic situation.

Initial Approach Fix (IAF): A geographic point at which an Instrument Approach is initiated. The IAF is normally defined electronically by navigational aids.

Instrument Approach: For the purposes of this paper an instrument approach is a non-radar controlled approach procedure for transitioning an aircraft from an Initial Approach Fix to a Final Approach Fix, thence to a runway. In flying an instrument approach, a pilot follows a published procedure and proceeds via his own navigation. Instrument approach procedures approved by the DOD for military aircraft are published in FLIP.

Instrument Flight Rules (IFR): A set of rules provided by the FAA for the conduct of flight. These rules direct specific behavior by both pilot and air traffic controller. A pilot operating in accordance with IFR is provides separation from other IFR aircraft by an air traffic control agency.

Jet Route: One of a system of flight paths specified for enroute navigation by the FAA. Jet routes are designed for

operation of aircraft between the altitudes of 18,000 feet (mean sea level) and flight level 450 (45,000 feet mean sea level). Jet routes are defined by specific compass bearings from ground based transmitters and are published in FLIP.

Low Altitude Airway: One of a system of flight paths specified for enroute navigation by the FAA. Low altitude airways are designed for aircraft operating between the altitudes of 1200 feet (above ground level) up to, but not including, 18,000 feet (mean sea level). The airways are defined by specific compass bearings from navigational aids and are published in FLIP.

Mean Time to Fly (MTF): The average time required for an aircraft of a given category to fly between two points without being delayed by conflicting traffic.

Missed Approach (MA): Failure to land after making an approach. A missed approach may be pre-planned, as in the case of a training maneuver, or spontaneous, as in the case of improper aircraft alignment with the runway. Occupation of the runway by another aircraft is another condition requiring a landing aircraft to execute a missed approach.

Runway Occupancy Time (ROT): The amount of time that an aircraft spends on the runway during takeoff or landing plus any additional time on the runway prior to takeoff or subsequent to landing.

Scheduling: The establishment of an arrival sequence for aircraft based on pre-flight planning data.

Sequencing: The ordering of arriving aircraft, with respect to their landing position, from first to last.

Standard Vectoring Routes (SVR): The routes normally used by controllers to maneuver aircraft from Arrival Fixes to the Final Approach Fix. These routes may be prescribed by published directives or they may be established by convention.

Tower: A control facility, located in close proximity to a runway, which provides visual monitoring and control of arriving and departing aircraft, and which exercises final clearance authority for use of the runway.

Visual Flight Rules (VFR): A set of rules provided by the FAA for the conduct of flight. Under VFR the pilot has more flexibility as to his actions than under IFR, and he retains total responsibility for the avoidance of other aircraft.

Assumptions and Limitations

The following assumptions and limitations apply to the development of the Dayton ACA simulation model:

(1) Consideration of the final approach and landing phases of flight is limited to Wright-Patterson AFB.

(2) The runway in use during any simulation run is Runway 23, the primary instrument runway at Wright-Patterson AFB.

(3) The effect of wind on the behavior of an aircraft is not considered.

(4) Altitude is considered to occur in discrete increments; that is vertical airspace can be thought of as a series of surfaces piled one on top of another. An aircraft can maneuver of a "surface" without conflicting with an aircraft on another "surface."

(5) Vectoring routes are limited to a discrete number of alternatives.

(6) Airspeed changes are considered to occur in discrete units.

(7) Separation distances between aircraft are in accordance with FAA and DOD criteria. They vary depending on aircraft category.

(8) Human error on the part of pilots or air traffic controllers is not considered in the simulation model.

(9) Unusual situations or emergency conditions are not considered in the simulation model.

Chapter 3

METHODOLOGY

The methodology in this research involves the construction of a simulation model of the Dayton ACA and its subsequent use as a tool for experimentation. The first step in model construction was to collect data to satisfy information requirements. Information was required in two primary areas: information on the physical composition of the Dayton ACA and information on the nature of the air activity within the Dayton ACA. The second step was to analyze the data and to validate the results in preparation for model construction. The third step was to develop the simulation model, itself, in the form of a GPSS computer program (8). The development process was based directly upon the information obtained from the data collection and analysis. The fourth step was to validate the model to insure that the model was a true representation of the Dayton ACA. Validation of the model marked the completion of phase one as described in the objective section. The last step in the methodology was to apply the simulation model to the remaining phases (two and three) established in the objective section.

Phase two called for experimentation with the simulation model. This was accomplished by altering the original validated model in a manner that would test the significance

of changes in ACA design and in ATC procedures. The computer output of the altered models, i.e. the experimental models, was compared to that of the validated model. The results of these experiments are recorded in Chapter 4. Phase three was not accomplished. This phase is discussed in Chapter 5 under Recommendations for Future Research.

This methodology chapter, therefore, is organized in accordance with the five steps described above and is a systematic elaboration of each step, beginning with data collection.

Data Collection

As noted above, information was required in two primary areas: the physical composition of the Dayton ACA and the nature of the air activity in the Dayton ACA. In both areas the primary emphasis was to collect data relevant to the role of Wright-Patterson AFB within the Dayton ACA since the simulation model was limited to handling air traffic to and from Wright-Patterson. Data collection on the physical composition of the Dayton ACA is presented first.

Composition of the Dayton ACA. For purposes of model construction, the data for the Dayton ACA dealt primarily with the physical location of the entities that make up the Dayton ACA: runways, navigational aids, air routes, arrival and departure routes, and geographical boundaries. Given the exact location of these entities, precise measurements of

distance relative to the runway at Wright-Patterson AFB were made. These measurements, in nautical miles, were used in constructing the simulation model.

Data pertaining to the physical characteristics of the Dayton ACA were extracted from FLIP and from other documents, maps, and charts obtained from Dayton Approach Control (3). FLIP Enroute High Altitude Chart H-3 was used as guidance for the jet route structure, Figure 3, that overlies the Dayton ACA. FLIP Enroute Low Altitude Charts L-11, L-21, and L-23 were used in plotting the low altitude airway structure which penetrates the controlled airspace of Dayton Approach Control. Figure 4 is a presentation of the low altitude airway structure in relation to the Dayton ACA.

Aircraft inbound to the Dayton ACA, on an IFR flight plan, proceed via the jet route structure or via the low altitude airway network and are transitioned to one of six arrival fixes (AFs) that service Wright-Patterson AFB. In the transitioning process, the responsibility of air traffic control of individual aircraft is transferred from the enroute air traffic control facility to Dayton Approach Control who then controls each aircraft's flight path to the runway at Wright-Patterson. The location of the six AFs and the associated air routes to Wright-Patterson were obtained in discussions with the Deputy Chief of the Dayton Approach Control (3). The air routes from the AFs to the runway are the Standard Vectoring Routes (SVRs) in the

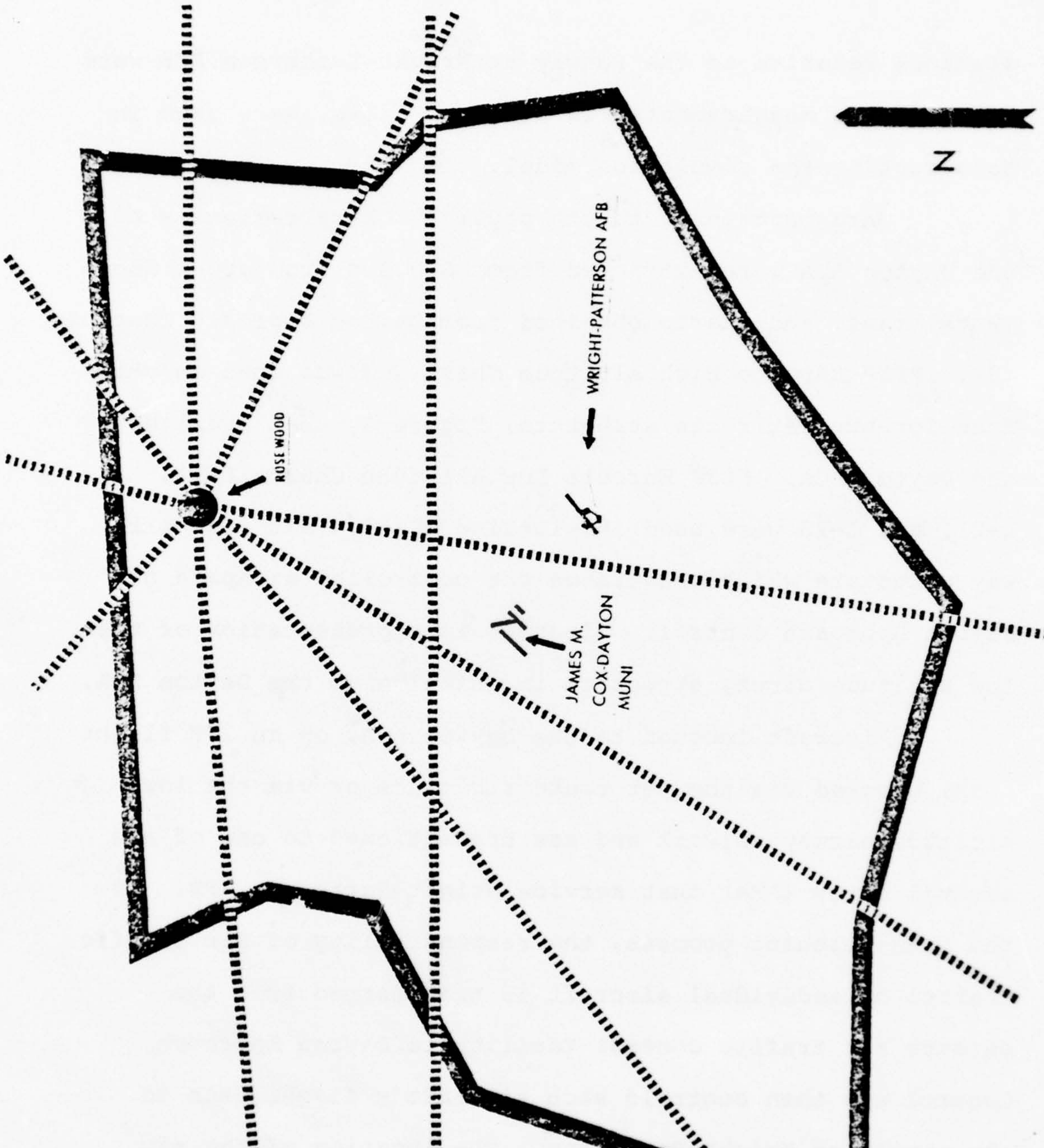

Figure 3. Jet Routes.

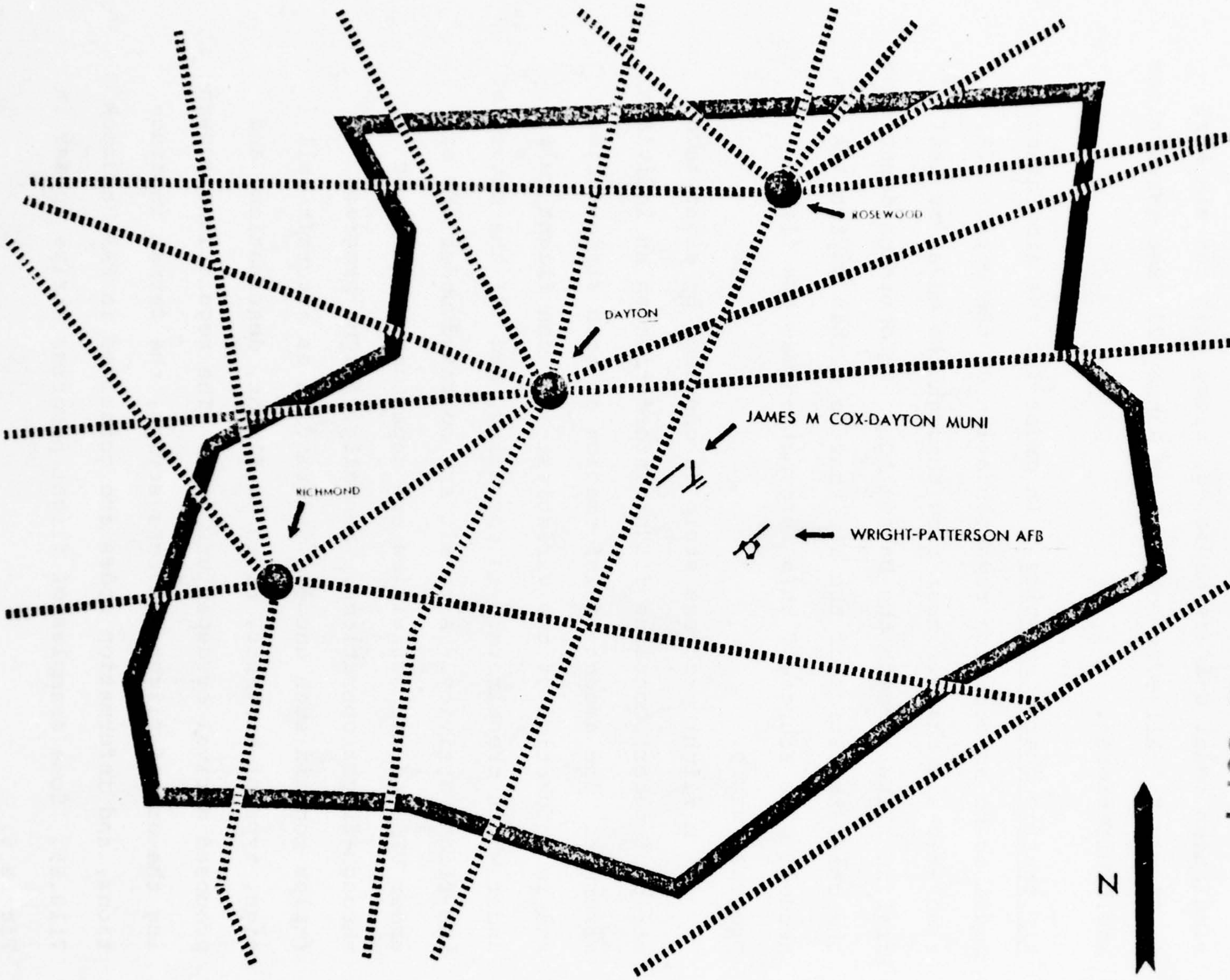

Figure 4. Low Altitude Airways.

simulation model and are depicted, along with the six AFs, in Figure 5. All SVRs converge on Runway 23 (see Assumptions and Limitations).

Air traffic characteristics. In order for the simulation model to be an accurate representation of the Dayton ACA, simulated air traffic must flow through the model as real traffic flows through the Dayton ACA. Information describing the characteristics of the air traffic within Dayton ACA was needed. The source of this information was the flight progress strip.

A flight progress strip (a one inch by eight inch strip of paper) contains flight information on an individual aircraft. The amount of information on each strip varies and is a function of two variables: (1) the flight rules under which the aircraft is operating, and (2) the nature of the flight activity. Aircraft are operated under IFR or under VFR and air activities are departure, arrival or through-flight operations. Normally, flight progress strips contain such encoded information as aircraft call sign, type of aircraft, route of flight, destination, and proposed arrival or departure time. The regulations governing the use of flight progress strips, the format instructions, and information codes are contained in FAA Handbook 7110.65. Some examples of flight progress strips appear in Figure 6.

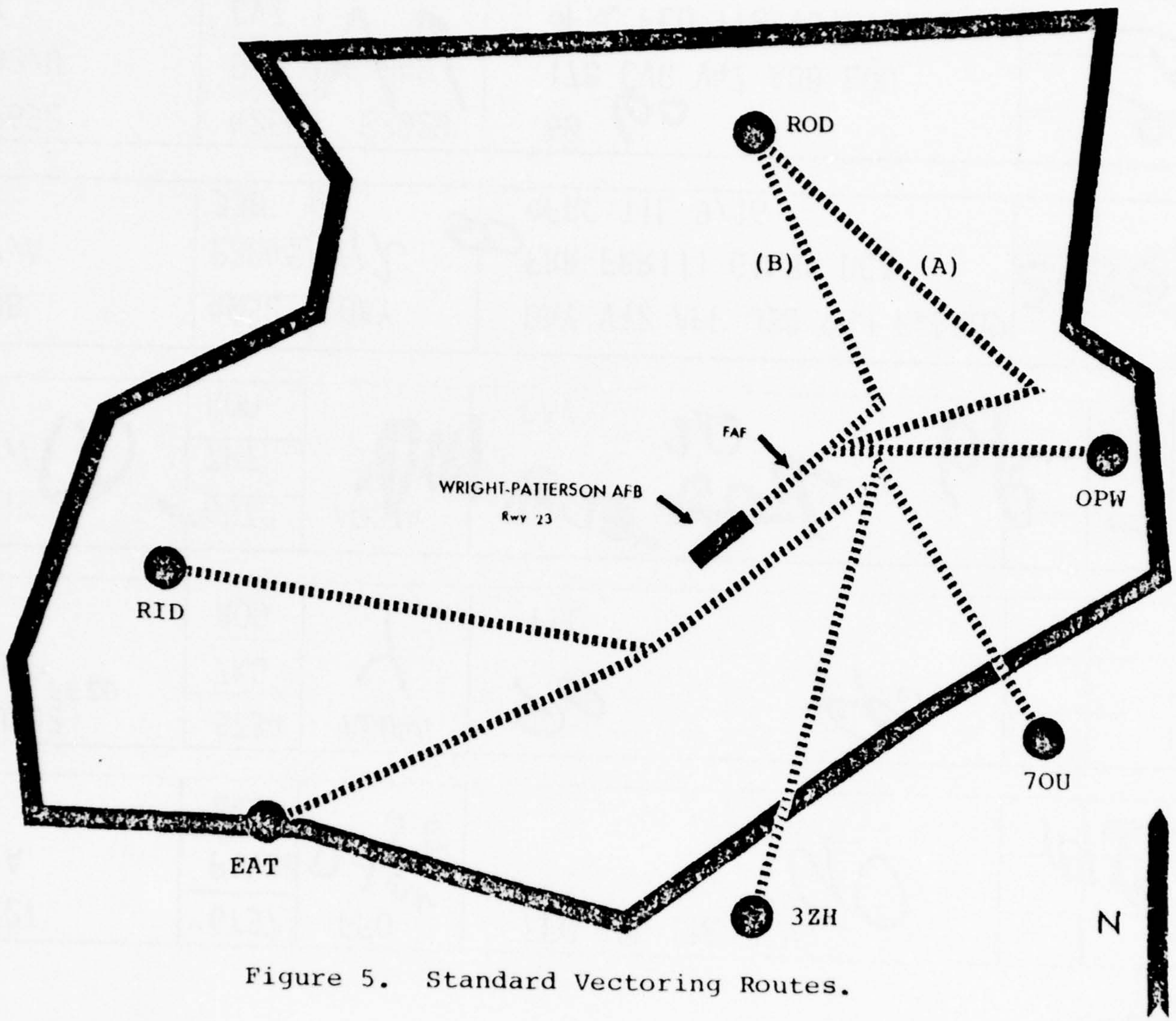

Figure 5. Standard Vectoring Routes.

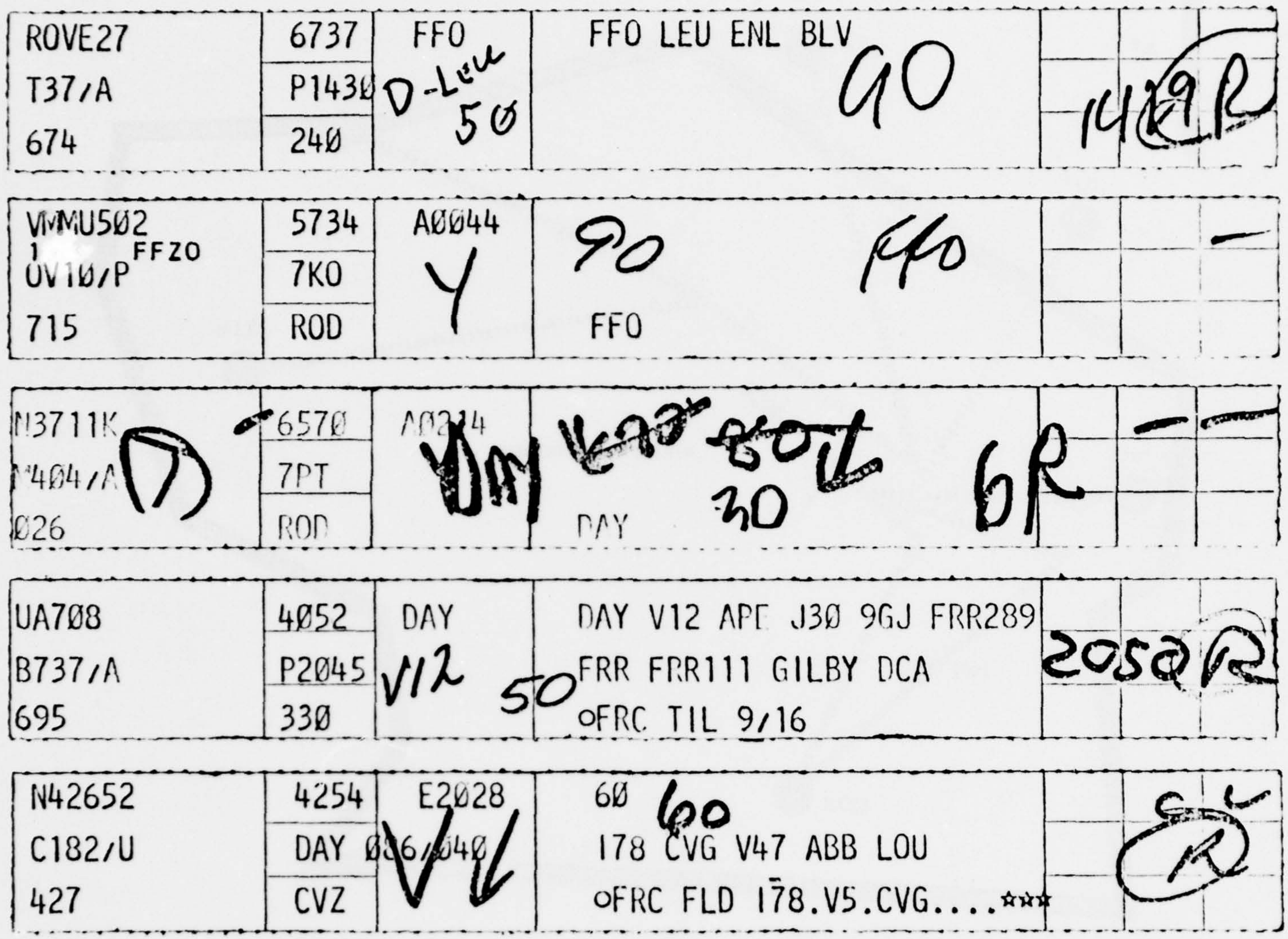

Figure 6. Sample Flight Progress Strips

For flights operating in accordance with IFR, flight progress strips are computer-generated and supplied to an air traffic controller before the aircraft identified on the strip enters his area of jurisdiction. The controller, himself, generates flight progress strips for aircraft operating in accordance with VFR when he initially establishes radio communications with the pilot. Air traffic controllers use the flight progress strips for planning purposes and for recording the time and nature of particular events associated with an aircraft. Examples of such recordings are the actual time of departure, the time an aircraft penetrates the controller's airspace, the time of initial radio contact, and the time of transition to another control facility.

Since flight progress strips are generated for every aircraft operating under the control of an air traffic control facility, they are a source of raw data to accurately indicate the characteristics of air activity in a given area (13). Analysis of flight progress strips can provide information on: (1) the volume of air traffic for any given time period, (2) the frequency and the types of air operations, (3) the types of aircraft that make up the air traffic, and (4) the volume of traffic using navigational facilities and selected airports located within a given area.

<u>Sampling procedure</u>. All the flight progress strips generated during a single day at a given air traffic control facility

are packaged, filed and retained for 90 days. In order to collect data to identify and analyze the characteristics of the air activity in the Dayton ACA, packages of flight progress strips were selected from the files of Dayton Approach Control. Seven packages were randomly selected from the files for the month of September, 1976 (one package was selected from among all of the "Sundays," one from among all the "Mondays," . . . , one from among all the Saturdays"). In this respect the selected flight progress strips represented an entire week of air operations. According to Puhala, September was typical month for air activity in the Dayton ACA. Nothing unusual occurred in September that would have created a greater or lesser amount of air traffic than is normally experienced (13).

The seven packages contained 4526 flight progress strips (a figure obtained by summing recorded daily totals). From this population a sample of 311 flight progress strips was selected. The selection plan for the sample was in accordance with a systematic sampling technique as outlined by Emory (5:153-154). Every fifteenth flight progress strip was selected after the first was randonly drawn.

The formula used to calculate the sample size was taken from Emory (5:150-152):

$\pm.06$ = desired maximum error;

$1.09\sigma p$ = .95 confidence level for estimating the interval within which to expect the population proportion;

σp = .03061 = standard error of the proportion (.06/1.96)

$\pi(1-\pi)$ = measure of population dispersion, here estimated as maximum = .25;

N = 4526 = population size;

$$\sigma p = \sqrt{\frac{\pi(1-\pi)}{n-1}} \cdot \sqrt{\frac{N-n}{N-1}}$$

$$.03061 = \sqrt{\frac{.25}{n-1}} \cdot \sqrt{\frac{4526-n}{4526-1}}$$

$$(.03061)^2 = \frac{.25}{n-1} \cdot \frac{4526-n}{4525}$$

$$4525(n-1)(.03061)^2 = .25(4526-n)$$

$$4.2398(n)-4.2398 = 1131.5-.25(n)$$

$$4.4898(n) = 1135.7398$$

n = 252.96 = sample size.

Determination of the minimum sample size was based on an estimated dispersion of .25: [.5(1-.5)], since there was no a priori knowledge of π, and on a desired confidence interval of 12%. Therefore, the minimum sample size to obtain the desired precision is approximately 253. Since there existed considerable uncertainty as to the frequency of occurrence of the various attributes of population aircraft, it was decided that the sample should be increased above the minimum. Thus, the sample size was set at 300 to insure sufficient accuracy would be obtained. To determine the selection interval for the systematic sample:

$$\frac{4526}{300} = 15.08$$

Selection of every 15th flight progress strip resulted in an actual sample of 311.

<u>Data file construction</u>. The data extracted from each flight progress strip was coded in the following manner and entered into a data file.

<u>Type Aircraft</u>: "C-172," "F-100," "B-727," etc.

<u>Arrival, Departure, Through-flight</u>: "A," "D," "T," respectively.

<u>Time</u>: In Greenwich Mean Time (to obtain local time substract 4 hours since September occurred during Daylight Savings Time).

<u>Destination, Departure Airport</u>: "D" = Dayton Municipal Airport, "W" = Wright-Patterson AFB, "O" = other.

<u>Last Fix</u> (the last navigational fix an arrival aircraft crossed prior to landing): Examples of coding are: "DAY" = the Dayton VORTAC; "FFO" = the Wright-Patterson VORTAC; etc.

<u>Previous Fix</u> (the next to last navigational fix an arrival aircraft crossed prior to landing): Encoded as above.

<u>Departure Fix</u> (the first navigational fix crossed after takeoff by a departure aircraft): Encoded as above.

Next Departure Fix (the second navigational fix crossed after takeoff by a departure aircraft): Encoded as above.

Flight Rules: "I" = Instrument Flight Rules, "V" = Visual Flight Rules.

Day: "1" = Sunday, "2" = Monday, . . . , "7" = Saturday.

Category (based on classification by airspeed: Cruise, maneuvering and final approach airspeeds in knots groundspeed):

"V" = 550,250,180

"W" = 500,220,170

"X" = 300,170,150

"Y" = 250,130,100

"Z" = 140,110,800

The data file contained 311 line entries, one line for each flight progress strip. Each data line contained the coded information described above. Figure 7 is a portion of the resultant data file. The data extracted from the flight progress strips is nominal level data and the data file was formatted to permit the use of the computer program Statistical Package for the Social Sciences (SPSS) in data analysis.

SPSS is an integrated system of computer programs designed to provide a unified and comprehensive package that enables the user to perform different types of data

```
ØØ1Ø 'C172'  'T'  1743 'Ø'  'MGY'  'ROD'  'Ø'  'Ø'  'V'  2  'Z'
ØØ2Ø 'C172'  'A'  1443 'D'  'MGY'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
ØØ3Ø 'OV1Ø'  'A'  ØØ44 'W'  'ROD'  '7KO'  'Ø'  'Ø'  'I'  2  'Y'
ØØ4Ø 'T37'  'D'  1429 'W'  'Ø'  'Ø'  'LEU'  'ENL'  'I'  2  'Y'
ØØ5Ø 'MO21'  'T'  1338 'Ø'  'OSU'  '7TR'  'Ø'  'Ø'  'I'  2  'Z'
ØØ6Ø 'C182'  'T'  2Ø28 'Ø'  'DAY'  'CVG'  'Ø'  'Ø'  'I'  2  'Z'
ØØ7Ø 'C172'  'A'  161Ø 'D'  'ROD'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
ØØ8Ø 'B727'  'D'  1812 'D'  'Ø'  'Ø'  'DAY'  'FLM'  'I'  2  'W'
ØØ9Ø 'B727'  'A'  1128 'D'  'RID'  'CVG'  'Ø'  'Ø'  'I'  2  'W'
Ø1ØØ 'C15Ø'  'A'  2139 'D'  'ROD'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø11Ø 'L188'  'A'  2Ø32 'W'  'OPW'  'APE'  'Ø'  'Ø'  'I'  2  'X'
Ø12Ø 'A37'  'D'  1535 'W'  'Ø'  'Ø'  'ROD'  'CRL'  'I'  2  'Y'
Ø13Ø 'F4'  'D'  1951 'W'  'Ø'  'Ø'  'IND'  'GLD'  'I'  2  'V'
Ø14Ø 'PA28'  'T'  Ø354 'Ø'  'MGY'  'ROD'  'Ø'  'Ø'  'V'  2  'Z'
Ø15Ø 'C15Ø'  'A'  2312 'W'  'ROD'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø16Ø 'B727'  'A'  Ø131 'D'  'RID'  'IND'  'Ø'  'Ø'  'I'  2  'W'
Ø17Ø 'C31Ø'  'T'  2ØØ4 'Ø'  'ROD'  'CVG'  'Ø'  'Ø'  'I'  2  'Y'
Ø18Ø 'PA28'  'A'  15Ø1 'D'  'Ø'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø19Ø 'BL26'  'D'  1257 'D'  'Ø'  'Ø'  'CVG'  'Ø'  'I'  2  'Z'
Ø2ØØ 'DC9'  'A'  21Ø7 'D'  '7UB'  '3GO'  'Ø'  'Ø'  'I'  2  'W'
Ø21Ø 'B727'  'D'  1856 'D'  'Ø'  'Ø'  'DAY'  'FWA'  'I'  2  'W'
Ø22Ø 'DC9'  'A'  1524 'D'  'ROD'  '7FK'  'Ø'  'Ø'  'I'  2  'W'
Ø23Ø 'B7Ø7'  'A'  1113 'D'  '3PZ'  'CMH'  'Ø'  'Ø'  'I'  2  'W'
Ø24Ø 'B727'  'D'  ØØØ1 'D'  'Ø'  'Ø'  'DAY'  '3PZ'  'I'  2  'W'
Ø25Ø 'C15Ø'  'D'  1822 'W'  'Ø'  'Ø'  'SGH'  'Ø'  'V'  2  'Z'
Ø26Ø 'BE9Ø'  'A'  13Ø8 'D'  'OSU'  'Ø'  'Ø'  'Ø'  'I'  2  'Z'
Ø27Ø 'C182'  'D'  1827 'D'  'Ø'  'Ø'  'DAY'  'CVG'  'I'  2  'Z'
Ø28Ø 'BE23'  'A'  2246 'D'  'Ø'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø29Ø 'C2Ø6'  'D'  1914 'D'  'Ø'  'Ø'  'SGH'  'Ø'  'V'  2  'Z'
Ø3ØØ 'C15Ø'  'A'  1323 'W'  'Ø'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø31Ø 'PA28'  'D'  18Ø9 'D'  'Ø'  'Ø'  'CVG'  'Ø'  'V'  2  'Z'
Ø32Ø 'BE55'  'A'  1722 'D'  'Ø'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø33Ø 'BE19'  'A'  19Ø4 'D'  'Ø'  'Ø'  'Ø'  'Ø'  'V'  2  'Z'
Ø34Ø 'PA24'  'T'  215Ø 'Ø'  'SGH'  'RID'  'Ø'  'Ø'  'V'  2  'Z'
Ø35Ø 'BE33'  'T'  1123 'Ø'  'MGY'  'ROD'  'Ø'  'Ø'  'V'  2  'Z'
Ø36Ø 'PA28'  'T'  1336 'Ø'  'ROD'  'CVG'  'Ø'  'Ø'  'V'  2  'Z'
Ø37Ø 'C31Ø'  'D'  2346 'D'  'Ø'  'Ø'  'ROD'  'MFD'  'V'  2  'Y'
Ø38Ø 'C172'  'T'  ØØ18 'Ø'  'ROD'  'MGY'  'Ø'  'Ø'  'V'  2  'Z'
Ø39Ø 'BE9Ø'  'A'  1234 'W'  'FFO'  '7OU'  'Ø'  'Ø'  'I'  5  'Z'
Ø4ØØ 'T39'  'A'  1535 'W'  'FFO'  '7OU'  'Ø'  'Ø'  'I'  5  'X'
Ø41Ø 'C13Ø'  'A'  Ø145 'W'  'FFO'  '7OU'  'Ø'  'Ø'  'I'  5  'X'
Ø42Ø 'T39'  'A'  1951 'W'  'ØET'  'CVG'  'Ø'  'Ø'  'I'  5  'X'
Ø43Ø 'F1Ø1'  'A'  1647 'W'  'FFO'  '7OU'  'Ø'  'Ø'  'I'  5  'V'
Ø44Ø 'BE55'  'A'  1356 'D'  'ROD'  '7PT'  'Ø'  'Ø'  'I'  5  'Z'
Ø45Ø 'CV58'  'D'  1224 'D'  'Ø'  'Ø'  'MIE'  'Ø'  'I'  5  'Z'
Ø46Ø 'C421'  'A'  112Ø 'O'  'Ø'  'Ø'  'Ø'  'Ø'  'I'  5  'Y'
Ø47Ø 'C421'  'D'  2157 'O'  'Ø'  'Ø'  'Ø'  'Ø'  'I'  5  'Y'
Ø48Ø 'T39'  'D'  1719 'W'  'Ø'  'Ø'  'ROD'  'MFD'  'I'  5  'X'
Ø49Ø 'PAZT'  'T'  1249 'Ø'  'MFD'  'CVG'  'Ø'  'Ø'  'I'  5  'Z'
Ø5ØØ 'BE95'  'T'  22Ø4 'Ø'  'MGY'  'ROD'  'Ø'  'Ø'  'V'  5  'Z'
Ø51Ø 'G159'  'A'  2Ø44 'O'  'ØET'  'IND'  'Ø'  'Ø'  'I'  5  'Z'
Ø52Ø 'C414'  'A'  1314 'O'  'ROD'  'FDY'  'Ø'  'Ø'  'I'  5  'Y'
```

Figure 7. Sample of Data File

analysis in a simple and convenient manner (12:1). SPSS Version 6 was used to evaluate the data file on the Honeywell 635 computer located at Headquarters, Air Force Logistics Command, Wright-Patterson AFB, Ohio.

Analysis of Flight Progress Strips

Analysis of the sample data (flight progress strips) was accomplished in three phases. The first phase was to observe the frequency of occurrence of various aircraft attributes. SPSS subprogram FREQUENCIES (12:194) was used initially to obtain descriptive presentations of the data. The data was then analyzed using the Chi-Square test for homogeneity of occurrence ratios (4:369-371, 380-382).

The second phase of analysis was to determine the degree to which one characteristic of system traffic is dependent upon some other characteristic. SPSS subprogram CROSSTABS (12:230) was used to produce 2-way crosstabulations of variables. The degree of dependency of the variables based on the distribution of frequency counts in the cross-tabulation tables was ascertained by the use of the Chi-Square test of dependency (4:376-378). This analysis was particularly useful in developing the simulation model since it permitted the assignment of various characteristics, on a percentage basis, to traffic being generated in the simulation.

The third phase of analysis was to identify the distribution of air activity. Information derived through this analysis was used to govern the generation of the various types of air activity within the simulation model.

Data analysis follows the three phases described above. Phase one, occurrence ratios, is presented first.

Occurrence ratios of attributes. Each aircraft in the sample was identified by seven characteristics: Operation, time, airport, route, flight rules, day and aircraft type. The frequency of occurrence of the various characteristics are shown below in Table 1. In addition to the characteristics shown in Table 1, the route of each aircraft was identified, in a general sense, by the last navigation fix prior to landing or the first navigation fix after departure. Based on the observed characteristics, several hypotheses were formulated to test the homogeneity of occurrence ratios.

The first hypothesis concerns types of operations. The hypothesis is that the typed of operations have homogeneous occurrence ratios.

H_0: $P(\text{Operation}_i) = 1/3$

H_1: Not

Operation:	A	D	T
Observed:	130	134	47
Expected:	$103.\overline{6}$	$103.\overline{6}$	$103.\overline{6}$
$\dfrac{(O_i - E_i)^2}{E_i}$:	6.69	8.88	30.97

Table 1

Characteristics of Traffic

	Total #	Total %	Arrivals %	Departures %	Through-Flights %
Operations:					
Arrival	130	41.8	-	-	-
Departure	134	43.1	-	-	-
Through-Flight	47	15.1	-	-	-
Airport:					
Dayton	153	58.0	60.8	55.2	-
Wright-Patterson	73	27.7	21.5	33.6	-
Other	38	14.4	17.7	11.2	-
Flight Rules:					
IFR	226	72.7	76.2	76.9	51.1
VFR	85	27.3	23.8	23.1	48.9
Day:					
Sunday	50	16.1	14.6	16.4	19.1
Monday	38	12.2	13.1	9.0	19.1
Tuesday	54	17.4	16.2	19.4	14.9
Wednesday	51	16.4	12.3	20.1	17.0
Thursday	35	11.3	13.8	8.2	12.8
Friday	45	14.5	16.2	14.2	10.6
Saturday	38	12.2	13.8	12.7	6.4
Aircraft Type:					
V	14	4.5	5.4	5.2	0
W	56	18.0	23.1	17.9	4.3
X	29	9.3	9.2	12.7	0
Y	34	10.9	11.5	10.4	10.6
Z	178	57.2	50.8	53.7	85.1

Notes on Table 1: There were 47 through-flights that did not use any airport. Under Airport, "Other" means any of the 10 small civilian airfields within the boundaries of the Dayton ACA.

$$\chi_s^2 = \sum \left[\frac{(O_i - E_i)^2}{E_i} \right] = 46.54 > \chi_c^2 = 9.21 \quad \alpha = .01 \quad \text{d.f.} = c-1 = 2$$

Therefore H_0 is rejected: The types of operations do not have homogeneous occurrence ratios. Lacking any other information, the best estimate of the actual occurrence ratios is the sample observations.

The airports at which arrivals and departures occur is an important consideration in developing the simulation model. The hypothesis was formulated that use of Dayton, Wright-Patterson, and "other" airports occur in homogeneous ratios:

H_0: $P(\text{Airport}_i) = 1/3$

H_1: Not

Airport:	D	W	O
Observed	38	73	153
Expected	88	88	88
$\frac{(O_i-E_i)^2}{E_i}$:	28.41	2.56	48.01

$\chi_s^2 = 78.98 > \chi_c^2 = 9.21 \quad \alpha = .01 \quad \text{d.f.} = c-1 = 2$

Therefore H_0 is rejected: The airports are not used in homogeneous ratios. The best estimate available of the actual occurrence ratios is the sample data.

The flight rules under which an aircraft is operating are important because they may effect the manner in which an aircraft is handled. The hypothesis is that IFR and VFR occur with equal probability.

H_0: P(IFR) = P(VFR) = 1/2

H_1: Not

Rules:	IFR	VFR
Observed:	226	85
Expected:	155.5	155.5
$\frac{(\lvert O_i - E_i \rvert - 1/2)^2}{E_i}$:	31.51	31.51

$$\chi_s^2 = \sum \left[\frac{(\lvert O_i - E_i \rvert - 1/2)^2}{E_i} \right]^* = 63.02 > \chi_c^2 = 6.63 \quad \alpha = .-01 \quad d.f.=1$$

Therefore H_0 is rejected: The probability of occurrence is not equal.

Finally, the occurrence ratios of aircraft types were hypothesized to be equal.

H_0: P(Aircraft Type_i) = 1/5

H_1: Not

Type:	1	2	3	4	5
Observed:	14	56	29	34	178
Expected:	62.2	62.2	62.2	62.2	62.2
$\frac{(O_i - E_i)^2}{E_i}$:	37.34	.618	17.72	12.78	215.58

$$\chi_s^2 = 284.05 > \chi_c^2 = 13.27 \quad \alpha = .01 \quad d.f.=4$$

Therefore H_0 is rejected: Aircraft types do not have homogeneous occurrence ratios.

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*This formula was required because of the number of cells.

The results of these tests indicate that in all cases the frequency of occurrence was not homogeneous. The frequencies observed in the sample are assumed to provide the best estimate of the actual occurrence ratios.

Dependency between attributes. The second phase of data analysis involved tests for dependency conducted on the following air traffic characteristics:

1. Operation - Aircraft Type
2. Airport - Aircraft Type
3. Flight Rules - Aircraft Type
4. Flight Rules - Airport
5. Airport - Arrival Route
6. Airport - Departure Route
7. Aircraft Type - Day of the Week
8. Aircraft Type - Time of Day
9. Airport - Operation

The first hypothesis tested concerned operation and aircraft type. The hypothesis is that operation and aircraft type occur independently.

H_0: $P(\text{Operation}_i | \text{Aircraft Type}_i) = P(\text{Operation}_i)$

H_1: Not

$\chi_s^2 = 22.99 > \chi_c^2 = 20.09 \quad \alpha = .01 \quad d.f. = 8$

Therefore H_0 is rejected: Dependency exists between type of aircraft and type of operation. The χ^2 contingency table used to revolve this hypothesis is shown in Table 2.

Table 2.

Crosstabulation: Aircraft Category and Operation

ARRDER

CAT	COUNT / ROW PCT / COL PCT / TOT PCT	ARRIVAL 1.	DEPARTR 2.	THRU FLT 3.	ROW TOTAL
FAST MOVER 0.	COUNT	7	7	0	14
	ROW PCT	50.0	50.0	0.	4.5
	COL PCT	5.4	5.2	0.	
	TOT PCT	2.3	2.3	0.	
AIR CARRIER 0.	COUNT	30	24	2	55
	ROW PCT	53.6	42.9	3.6	18.0
	COL PCT	23.1	17.9	4.3	
	TOT PCT	9.6	7.7	0.6	
MEDIUM 0.	COUNT	12	17	0	29
	ROW PCT	41.4	58.6	0.	9.3
	COL PCT	9.2	12.7	0.	
	TOT PCT	3.9	5.5	0.	
SMALL 0.	COUNT	15	14	5	34
	ROW PCT	44.1	41.2	14.7	10.9
	COL PCT	11.5	10.4	10.6	
	TOT PCT	4.8	4.5	1.6	
SLOW 0.	COUNT	66	72	40	178
	ROW PCT	37.1	40.4	22.5	57.2
	COL PCT	50.8	53.7	85.1	
	TOT PCT	21.2	23.2	12.9	
COLUMN TOTAL		130	134	47	311
		41.8	43.1	15.1	100.0

CHI SQUARE = 22.98888 WITH 8 DEGREES OF FREEDOM

Given an aircraft type, the bivariate probabilities shown in the contingency table, therefore, are the best information available for designating an aircraft generated in the model as an arrival, a departure or a through-flight.

The second hypothesis is that airport usage occurs independently of aircraft type.

H_0: $P(\text{Airport}_i | \text{Aircraft Type}_i) = P(\text{Airport}_i)$

H_1: Not

$\chi_s^2 = 139.11 > \chi_c^2 = 20.10 \quad \alpha = .01 \quad \text{d.f.} = 8$

Therefore H_0 is rejected: Dependency exists between airport usage and aircraft type. Table 3 is the χ^2 contingency table used to revolve the hypothesis. The information in the contingency table will be used to assign aircraft, generated in the model, to an airport.

The third hypothesis is that flight rules are independent of aircraft type.

H_0: $P(\text{IFR} | \text{Aircraft Type}_i) = P(\text{IFR} | \text{Airfraft Type}_j)$

$= P(\text{IFR})$

H_1: Not

$\chi_s^2 = 63.44 > \chi_c^2 = 13.277 \quad \alpha = .01 \quad \text{d.f.} = 4$

Therefore H_0 is rejected: Dependency exists between flight rules and aircraft type. Given an aircraft type, the best estimate available on the percentage of the type of aircraft that will be IFR is the percentage obtained from

Table 3.

Crosstabulation: Aircraft Category and Airport

CAT	COUNT ROW PCT COL PCT TOT PCT	OTHER	WPAFB	DAYTON	ROW TOTAL
	0.	0	11	3	14
FAST MVR		0.	78.6	21.4	5.3
		0.	15.1	2.0	
		0.	4.2	1.1	
	0.	0	4	50	54
CARRIER		0.	7.4	92.6	20.5
		0.	5.5	32.7	
		0.	1.5	18.9	
	0.	1	28	0	29
MEDIUM		3.4	96.6	0.	11.0
		2.6	38.4	0.	
		0.4	10.6	0.	
	0.	9	11	9	29
SMALL		31.0	37.9	31.0	11.0
		23.7	15.1	5.9	
		3.4	4.2	3.4	
	0.	28	19	91	138
SLOW		20.3	13.8	65.9	52.3
		73.7	26.0	59.5	
		10.6	7.2	34.5	
	COLUMN TOTAL	38	73	153	264
		14.4	27.7	58.0	100.0

CHI SQUARE = 139.11394 WITH 8 DEGREES OF FREEDOM

the sample. The contingency table used to resolve this hypothesis is shown in Table 4.

The third hypothesis dealing with flight rules is that flight rules are independent of airport.

H_0: $P(IFR|Airport_i) = P(IFR|Airport_j) = P(IFR)$

H_1: Not

$\chi_s^2 = 9.25 > \chi_c^2 = 9.21 \quad \alpha=.01 \quad d.f.=2$

Therefore H_0 is rejected: Dependency exists between airport used and flight rules. Since the conditional probabilities are not equal, the best estimate of the actual probabilities are those obtained from the sample data. This information will be used to assign flight rules to an aircraft based on its airport of origin or destination. The χ^2 contingency table used to resolve this hypothesis is shown in Table 5.

Airport was next crosstabulated with route for both arrivals and departures. It should be noted that certain combinations of airport and route are precluded by airspace divisions within the Dayton ACA. For example, an arrival via 7OU cannot go to Dayton. Similarly, a departure from Wright-Patterson cannot go to 9WJ. These limitations result in contingency tables that do not meet the accepted minimum cell size criteria and are technically invalid. Since most of the zero value cells are known to have zero value in the population of actual air traffic, this technical limitation

Table 4.

Crosstabulation: Aircraft Category

and Flight Rules

CAT	COUNT / ROW PCT / COL PCT / TOT PCT	IFR 20.	VFR 21.	ROW TOTAL
	0.	14	0	14
FAST MOVER		100.0	0.	4.5
		6.2	0.	
		4.5	0.	
	0.	56	0	56
AIR CARRIER		100.0	0.	18.0
		24.8	0.	
		18.0	0.	
	0.	28		29
MEDIUM		96.6	3.4	9.3
		12.4	1.2	
		9.0	0.3	
	0.	29	5	34
SMALL		85.3	14.7	10.9
		12.8	5.9	
		9.3	1.6	
	0.	99	79	178
SLOW		55.6	44.4	57.2
		43.8	92.9	
		31.8	25.4	
	COLUMN TOTAL	226	85	311
		72.7	27.3	100.0

CHI SQUARE = 63.44043 WITH 4 DEGREES OF FREEDOM

Table 5.

Crosstabulation: Airport and Flight Rules

DESDEP	COUNT / ROW PCT / COL PCT / TOT PCT	IFR 20.	VFR 21.	ROW TOTAL
OTHER	0.	34	4	38
		89.5	10.5	14.4
		16.8	6.5	
		12.9	1.5	
WRIGHT PAT	0.	61	12	78
		83.6	16.4	27.7
		30.2	19.4	
		23.1	4.5	
DAYTON	0.	107	46	153
		69.9	30.1	58.0
		53.0	74.2	
		40.5	17.4	
	COLUMN TOTAL	202	62	264
		76.5	23.5	100.0

CHI SQUARE = 9.25 WITH 2 DEGREES OF FREEDOM

is considered irrelevant. The contingency tables shown in Tables 6 and 7 are therefore considered to be simple probability tables and the resulting percentages are treated as representative of population values.

The type of aircraft is an important characteristic of a traffic element as it will determine speed, following distances, and times to fly between geographic point. It was valuable to determine if aircraft type is dependent on other characteristics. Thus far, the dependency of aircraft type has been evaluated with respect to type of operation, airport, and flight rules. Two additional hypotheses were tested regarding aircraft type.

The first hypothesis is that aircraft types occur independent of the day of the week.

H_0: $P(\text{Aircraft Type}_i | \text{Day}_i) = P(\text{Aircraft Type}_i | \text{Day}_j)$

$= P(\text{Aircraft Type}_i)$

H_1: Not

$\chi_s^2 = 18.88 < \chi_c^2 = 34.81 \quad \alpha = .01 \quad d.f. = 18$

Therefore H_0 cannot be rejected: There is insufficient evidence to assess dependency between aircraft type and day of the week. Consequently, aircraft in the simulation will be assigned an aircraft type without regard to the day of the week. The χ^2 contingency table used to resolve this hypothesis is shown in Table 8.

Table 6.

Crosstabulation: Airport and Arrival Routes

APT / RTE (COUNT, ROW PCT, COL PCT, TOT PCT)	ROD 1.	RID 2.	7OU 3.	3ZH 4.	EAT 5.	7UB 9.	OPW 10.	ROW TOTAL
1. OTHERS	10	3	0	0	2	1	2	18
	55.6	16.7	0.	0.	11.1	5.6	11.1	18.2
	35.7	12.5	0.	0.	15.4	7.7	13.3	
	10.1	3.0	0.	0.	2.0	1.0	2.0	
2. WPAFB	3	1	5	1	4	0	13	27
	11.1	3.7	18.5	3.7	14.8	0.	48.1	27.3
	10.7	4.2	100.0	100.0	30.8	0.	86.7	
	3.0	1.0	5.1	1.0	4.0	0.	13.1	
3. DAYTON	15	20	0	0	7	12	0	54
	27.8	37.0	0.	0.	13.0	22.2	0.	54.5
	53.6	83.3	0.	0.	53.8	92.3	0.	
	15.2	20.2	0.	0.	7.1	12.1	0.	
COLUMN TOTAL	28	24	5	1	13	13	15	99
	28.3	24.2	5.1	1.0	13.1	13.1	15.2	100.0

CHI SQUARE = 67.94834 WITH 12 DEGREES OF FREEDOM

Table 7.

Crosstabulation: Airport and Departure Routes

APT (COUNT / ROW PCT / COL PCT / TOT PCT) \ RTE	IROD 1.	RID 2.	7OU 3.	3ZH 4.	EAT 5.	7MG 6.	9WJ 7.	7UG 8.	ROW TOTAL
1. OTHER	3	5	0	0	3	2	1	1	15
	20.0	33.3	0.	0.	20.0	13.3	6.7	6.7	14.6
	15.0	23.8	0.	0.	14.3	8.3	50.0	10.0	
	2.9	4.9	0.	0.	2.9	1.9	1.0	1.0	
2. WPAFB	7	10	4	1	6	6	0	1	35
	20.0	28.6	11.4	2.9	17.1	17.1	0.	2.9	34.0
	35.0	47.6	100.0	100.0	28.6	25.0	0.	10.0	
	6.8	9.7	3.9	1.0	5.8	5.8	0.	1.0	
3. DAYTON	10	6	0	0	12	16	1	8	53
	18.9	11.3	0.	0.	22.6	30.2	1.9	15.1	51.5
	50.0	28.6	0.	0.	57.1	66.7	50.0	80.0	
	9.7	5.8	0.	0.	11.7	15.5	1.0	7.8	
COLUMN TOTAL	20	21	4	1	21	24	2	10	
	19.4	20.4	3.9	1.0	20.4	23.3	1.9	9.7	100.0

CHI SQUARE = 22.67692 WITH 14 DEGREES OF FREEDOM

Table 8.

Crosstabulation: Aircraft Category and Day

CAT (COUNT / ROW PCT / COL PCT / TOT PCT)	SUNDAY 1.	MONDAY 2.	TUESDAY 3.	WEDNESDAY 4.	THURSDAY 5.	FRIDAY 6.	SATURDAY 7.	ROW TOTAL
0. AIR CARRIER	8	8	12	6	7	9	6	56
	14.3	14.3	21.4	10.7	12.5	16.1	10.7	18.0
	16.0	21.1	22.2	11.8	20.0	20.0	15.8	
	2.6	2.6	3.9	1.9	2.3	2.9	1.9	
0. SMALL	5	5	6	4	7	7	0	34
	14.7	14.7	17.6	11.8	20.6	20.6	0	10.9
	10.0	13.2	11.1	7.8	20.0	15.6	0.	
	1.6	1.6	1.9	1.3	2.3	2.3	0.	
0. SLOW	28	23	29	36	16	21	25	178
	15.7	12.9	16.3	20.2	9.0	11.8	14.0	57.2
	56.0	60.5	53.7	70.6	45.7	46.7	65.8	
	9.0	7.4	9.3	11.6	5.1	6.8	8.0	
3. OTHER	9	2	7	5	5	8	7	43
	20.9	4.7	16.3	11.6	11.6	18.6	16.3	13.8
	18.0	5.3	13.0	9.8	14.3	17.8	18.4	
	2.9	0.6	2.3	1.6	1.6	2.6	2.3	
COLUMN TOTAL	50	38	54	51	35	45	38	311
	16.1	12.2	17.4	16.4	11.3	14.5	12.2	100.0

CHI SQUARE = 18.88173 WITH 18 DEGREES OF FREEDOM

The second hypothesis is that aircraft type occurs independently of the time of day (one hour periods).

H_0: $P(\text{Aircraft Type}_i | \text{Time}_i) = P(\text{Aircraft Type}_i | \text{Time}_j)$

$= P(\text{Aircraft Type}_i)$

H_1: Not

$\chi_s^2 = 6.25 < \chi_c^2 = 20.09 \quad \alpha = .01 \quad \text{d.f.} = 8$

Therefore H_0 cannot be rejected: There is insufficient evidence to assess dependency between aircraft type and time of day. The contingency table used to resolve this hypothesis is shown in Table 9. The table required that "time" be collapsed into three periods. The time period labeled "Daytime" covers the nine busiest hours of the day.

The final hypothesis tested deals with the relationship between operation and airport. The hypothesis is that operation is independent of airport.

H_0: $P(\text{Operation}_i | \text{Airport}_i) = P(\text{Operation}_i | \text{Airport}_j)$

$= P(\text{Operation}_i)$

H_1: Not

$\chi_s^2 = 1.73 < \chi_c^2 = 9.21 \quad \alpha = .01 \quad \text{d.f.} = 2$

Therefore H_0 cannot be rejected: There is insufficient evidence to assess dependency between operation and airport. The contingency table used to resolve this hypothesis is shown in Table 10.

Dependency was found in all but the last three tests. The fact that aircraft type occurs independent of either day

Table 9.

Crosstabulation: Time and Aircraft Category

TIME	COUNT / ROW PCT / COL PCT / TOT PCT	CAT: FAST MVR 0.	CARRIER 0.	MEDIUM 0.	SMALL 0.	SLOW 0.	ROW TOTAL
NIGHT	1.	3	21	12	8	33	77
		3.9	27.3	15.6	18.4	42.9	34.1
		21.4	37.5	42.9	27.6	33.3	
		1.3	9.3	5.3	3.5	14.6	
EARLY	2.	0	2	1	0	6	9
		0.	22.2	11.1	0.	66.7	4.0
		0.	3.6	3.6	0.	6.1	
		0.	0.9	0.4	0.	2.7	
DAYTIME	3.	11	33	15	21	60	148
		7.9	23.6	10.7	12.0	42.9	61.9
		78.6	58.9	53.6	72.4	60.6	
		4.9	14.6	6.6	9.3	26.5	
	COLUMN TOTAL	14	56	28	29	99	226
		6.2	24.8	12.4	12.8	43.8	100.0

CH[illegible] SQUARE = [illegible].24562 WITH 8 DEGREES OF FREEDOM

Table 10.

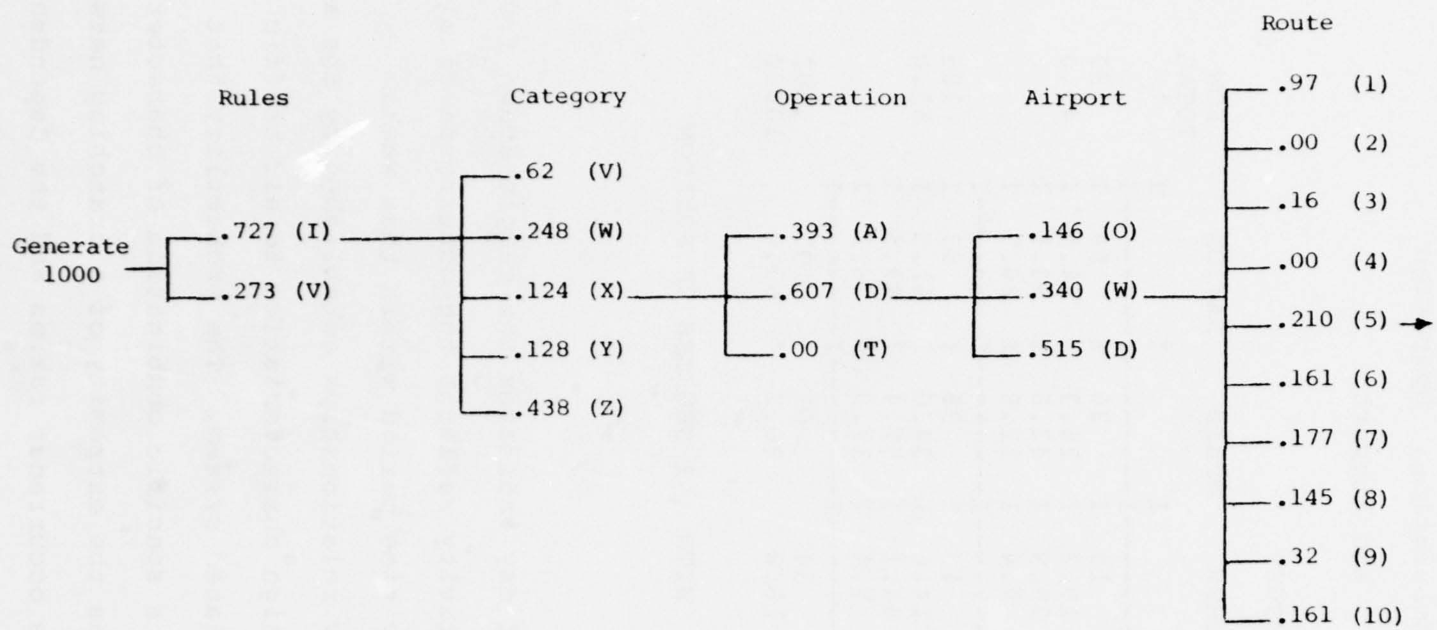
Crosstabulation: Operation and Airport

ARRDEP	COUNT / ROW PCT / COL PCT / TOT PCT	DESDEP: OTHER	WPAFB	DAYTON	ROW TOTAL
ARRIVAL	1.	19	26	54	99
		19.2	26.3	54.5	49.0
		55.9	42.6	50.5	
		9.4	12.9	26.7	
DEPARTR	2.	15	35	53	103
		14.6	34.0	51.5	51.0
		44.1	57.4	49.5	
		7.4	17.3	26.2	
	COLUMN TOTAL	34	61	107	202
		16.8	30.2	53.0	100.0

CHI SQUARE = 1.72927 WITH 2 DEGREES OF FREEDOM

of the week or time of day indicates the sample drawn from an entire week of air activity reflects the occurrence of aircraft types during any time period within that week.

The dependency relationships established by the above tests were used to assign characteristics to air traffic generated in the simulated system. The probability that an aircraft will possess a specific combination of characteristics can be viewed as the extremity of a branching network; Figure 8 shows how the occurrence ratios and the dependency



Example: Out of 1000 aircraft generated in the system, the number of IFR, Category X, Departures from WPAFB that used Route 5 = 1000 (.727)(.124)(.607)(.340)(.210) = 3.9 ≈ 4

Figure 8. Branching Network

relationships were used to assign characteristics. The number of aircraft possessing the combination of characteristics contained in each branch is the product of the probabilities contained in that branch and the number that entered the network.

Distribution of air activity. An important element in the simulation model is the rate at which aircraft arrive at and depart from Wright-Patterson AFB. As a means of identifying the distribution of air traffic, two procedures were employed. First, the distribution of IFR departures from Wright-Patterson was determined using curve-fit procedures (4:371-376). Second, the total number of air operations occurring during certain peak hours was used to determine the number of IFR departures from Wright-Patterson based on the probability of an air operation having that combination of characteristics. The results of these two procedures were then compared.

Analysis of the sample of 311 aircraft previously described indicated that the period from 1000 to 1900 had the greatest amount of aircraft activity. In addition, the traffic during that period was relatively constant. A χ^2 test for homogeneity of occurrence ratios was conducted as follows:

H_0: $P(\text{Hour}_i) = 1/9$

H_1: at least one not equal

$$\chi_s^2 = \sum \left[\frac{(O_i - E_i)^2}{E_i} \right]$$

Hour	Obs	Exp	$\frac{(O_i-E_i)^2}{E_i}$
1	23	22.11	.0358
2	18	22.11	.7640
3	26	22.11	.6844
4	22	22.11	.0005
5	18	22.11	.7640
6	18	22.11	.7640
7	23	22.11	.0358
8	25	22.11	.3777
9	26	22.11	.6844
			4.1106

$\chi_c^2 = 20.090 \quad \alpha = .01 \quad d.f. = c-1 = 8$

$\chi_s^2 = 4.11 < \chi_c^2 = 20.09$

Therefore χ_s^2 falls within the acceptance region and H_0 cannot be rejected. This result indicates that during the nine-hour period sampled, the hours are relatively homogeneous with respect to the rate of aircraft activity.

Based on the result of the foregoing analysis, the flight progress strips were obtained for all departures from Wright-Patterson during the priod from 1000 to 1900 on the busiest day in September, 1976. There were 51 such departures

recorded. The hypothesis was then formulated that these observed departures were obtained from a population following a Poisson distribution.

H_0: x~Poisson (λ)

H_1: Not

The random variable x is defined as the number of departures in a ten minute period. There were 54 such 10 minute periods observed. The parameter λ of the Poisson distribution was estimated from the sample mean arrivals per period ($\overline{x}$). The hypothesis test was resolved as shown in Table 11.

Table 11.

Chi-Square Goodness-of-Fit Test

x	f(x)	Exp	Obs	$(O_i-E_1)^2/E_i$
0	.3889	21.00	24	.4286
1	.3673	19.83	16	.7397
2	.1734	9.36	10	.0438
3 or more	.0704	3.80	4	.0104
				1.2225

$\overline{x} = .9444 = \lambda$

$\chi_c^2 = 9.210 \quad \alpha=.01 \quad d.f.=4-1-1=2$

$\chi_c^2 = 1.222 < \chi_s^2 = 9.21$

Therefore χ_s^2 falls within the acceptance region and H_0 cannot be rejected. This result indicates that the nine-

hour sample of departures was taken from a population of departures following a Poisson distribution with a parameter λ of .9444.

The f(x) value in the χ^2 table was obtained using the formula $f(x) = \frac{\lambda^x}{x!} e^{-\lambda}$ (4:173). The computed f(x) represents the probability that x will take on a specific value. The probability value for x = 3 or more is the cumulative probability of all 10 minute periods having 3 or more departures.

To confirm the conclusion stated above, a second hypothesis was formulated: The mean times between departures observed in the nine-hour period follow an exponential distribution.

H_0: $x \sim \text{Exp}(\lambda)$

H_1: Not

The random variable x is defined as the mean time between departures. The parameter λ of the exponential distribution was estimated from the sample mean time between arrivals ($\bar{x}$). The hypothesis test was resolved using the Kolmogorov-Smirnov test on maximum differences (4:382-386). The critical value for the maximum difference (MAX D_c) was obtained from Lilliefor's table of computed values. The sample maximum difference value (MAX D_s) was computed as shown in Table 12, where:

$\bar{x} = 10.657$

$1/\bar{x} = .09383 = \lambda$

Table 12.

Kolmogorov-Smirnov Test

Group	Boundary	F(x)	#/n	S(x)	D
Less than .5		.0488	0	0	.0488
	.5				
1-2		.2134	14/15	.2800	.0666
	2.5				
3-4		.3430	21/50	.4200	*.0770*
	4.5				
5-6		.4567	25/50	.5000	.0433
	6.5				
7-8		.5507	29/50	.5800	.0293
	8.5				
9-10		.6285	32/50	.6400	.0115
	10.5				
11-12		.6896	34/50	.6800	.0096
	12.5				
13-14		.7433	37/50	.7400	.0033
	14.5				
15-16		.7878	39/50	.7800	.0078
	16.5				
17-18		.8245	42/50	.8400	.0155
	18.5				
19-20		.8534	43/50	.8600	.0066
	20.5				
21-22		.8788	44/50	.8800	.0012
	22.5				
23-24		.8997	44/50	.8800	.0197
	24.5				
25-26		.9171	45/50	.9000	.0171
	26.5				
27-28		.9308	46/50	.9200	.0108
	28.5				
More than	28.5	1.0000	50/50	1.0000	0

MAX D_x = .0770

MAX $D_c = \sqrt{\frac{1.25}{N}} = .1768$

The results obtained from Table 12 indicate that MAX D_s falls within the acceptance region and H_0 cannot be rejected. Failure to reject the H_0 indicates the sample

of times between departures was taken from an exponentially distributed population with a mean time between departures of 10.657 minutes.

The F(x) value in the Kolmogorov-Smirnov table was obtained using the formula: $F(x) = 1-e^{-\lambda x}$ (4:214), where x is the group boundary. F(x) is the cumulative probability an observed time between departures will be less than x. For example, F(14.5) is the probability an observed mean time between departures will be less than 14.5

$$F(14.5) = 1-e^{-(.09383)(14.5)}$$

$$= 1-e^{-1.360} = 1-.2566 = .7433$$

It was established in the previous section that air operations are equally likely to occur during any day of the week. It was also established earlier in this section that air operations are equally likely during the nine busiest daylight hours. Based on these contentions, the entire 63 hours (9 hours for 7 days) were treated as a homogeneous mass and the mean number of operations per hour was determined from the sample. The computation was as follows:

Day	AO	$\overline{AO}$
1	34	$3.\overline{77}$
2	23	$2.\overline{55}$
3	31	$3.\overline{44}$
4	29	$3.\overline{22}$
5	20	$2.\overline{22}$
6	25	$2.\overline{77}$
7	27	3.00
		21.00 ÷ 7 = 3 AO/hr

Where AO = Air Operation. AO/hr was increased by a scaling factor of 14.553 to give an estimate of the mean number of operations per hour in the population.

$$14.553 \times 3 \text{ AO/hr} = 43.66 \text{ AO/hr}$$

The scaling factor is based on the sample size as a percentage of the population.

$$\frac{4526}{311} = 14.553$$

Figure 9 shows the distribution of daily means after scaling. During the 63 hours being considered, an air operation occurs every 1.374 minutes or every 82.4 seconds. This number was truncated and used as the parameter lambda of an exponential distribution. In the simulation model, the computer generates 5000 exponentially-distributed air operations over a period of 409,918 seconds. These air operations were assigned characteristics in accordance with the probabilities previously developed. Consequently, 497 IFR departures from Wright-Patterson were generated. This means there were 824 seconds or 13.7 minutes between departures.

The curve-fit procedures presented earlier in this section indicated a mean time between departures of 10.66 minutes. However, this value was obtained by sampling day 1 which, as shown above, had a sample mean number of operations of $3.\overline{77}$. Therefore, $14.553 \times 3.\overline{77}$ AO/hr = 54.98 AO/hr or one operation every 1.092 minutes or every 65.5 seconds. Using 65 for the same 5000 generations gives 654 seconds or 10.90 minutes between departures. $10.66 \approx 10.90$.

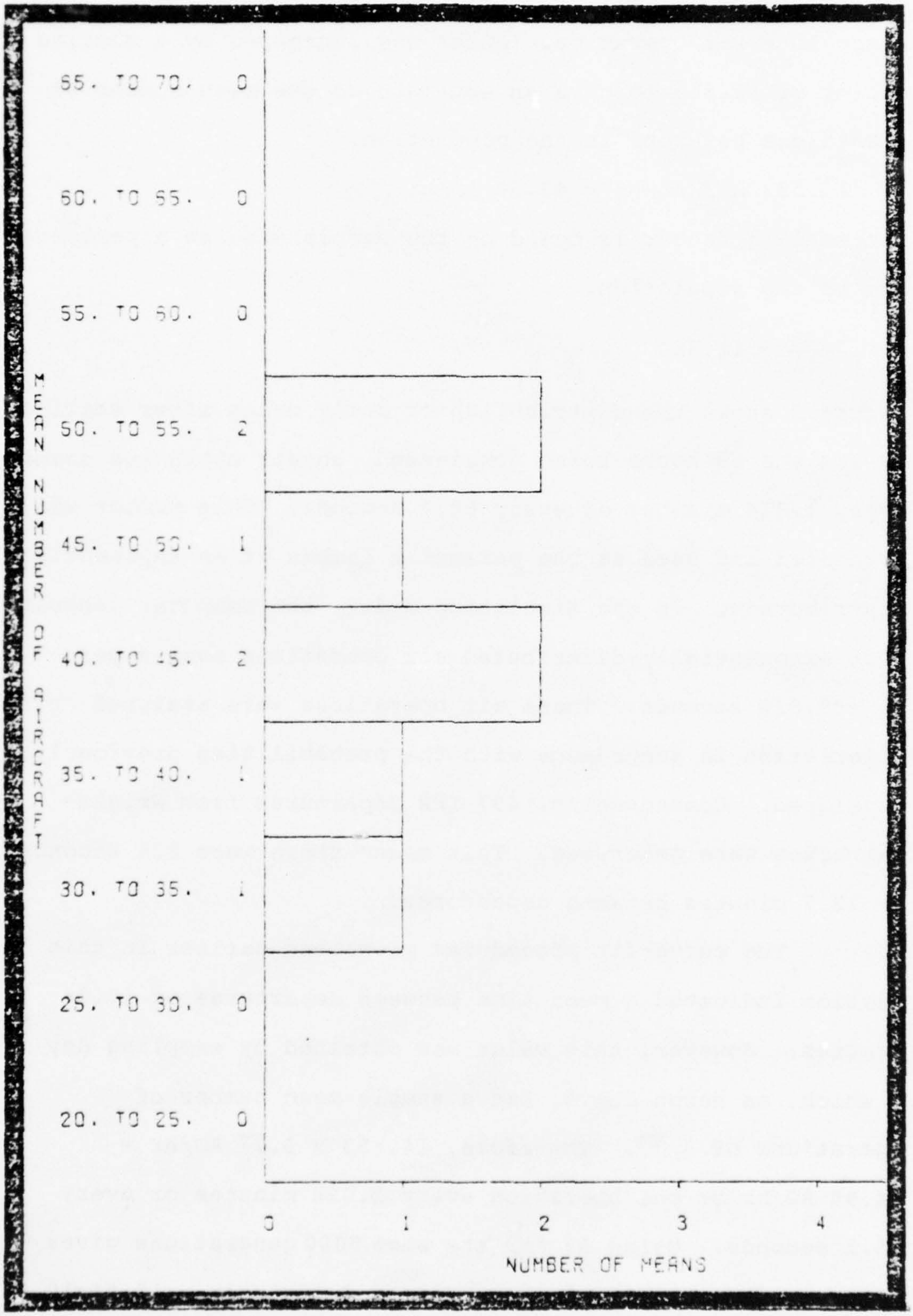


Figure 9. Aircraft per Hour.

On the basis of the foregoing analysis it was concluded that times between air operations are exponentially distributed with a mean time between operation of 82 seconds. Air activity was generated in the simulation model in accordance with this distribution.

Development

Morris described the development of a model as a procedure involving three concepts. The first concept can be usefully viewed as ". . . a process of enrichment or elaboration [11:B-709]." That is, the model is initially very simple but is elaborated upon until it evolves into a reflection, as close as possible, of the actual situation being modeled.

The second concept deals with the starting point for the elaboration process. The starting point should be determined by ". . . analogy or association with previously well developed logical structures . . .[11:B-709]."

The final concept is an extension of the first and suggests that the ". . . elaboration or enrichment involves at least two looping or alternation procedures [11:B-709]." These looping procedures are explained as follows. The first loop occurs between modification of the model and confrontation by the data. The model, confronted by the data, is tested and a modification results which is again confronted by the data.

The second loop occurs between the deductive tractability of the model and the assumptions upon which it is based. If the model is tractable, one returns to the assumptions and elaborates upon them. If, on the other hand, the model is not tractable, one returns to the assumptions and simplifies them. The two looping procedures progressively refine both the model and its underlying assumptions (11: B-709).

The development of a simulation model for the Dayton ACA adhered to the formula described by Morris. The starting point for the model was based on established concepts. Research described earlier under Literature Review indicates simulation has been applied successfully in evaluating ACA configurations. In particular, simulation based queuing theory has been used by Gabrielli and Mohleji (6:1-4; 10: 1-1 to 1-4).

The initial model was very simple and ignored many aspects of the terminal environment that were eventually included. It consisted of two arrival routes and a single destination. Aircraft flowing through this model were characterized as homogeneous in nature and were not distinguished, one from another, by differences in altitude, airspeed, or ROT. Furthermore, variation in air traffic delay times and aircraft departures were not considered for the initial model.

From this starting point, the model was elaborated through a stepwise inclusion of the complicating factors (addressed below) until a basic scenario was developed. At each step in the elaboration process, the model was evaluated through the application of the two looping procedures recommended by Morris (11:B-709). The model was modified and tested repeatedly at each step to insure its behavior was as expected. In addition, the results obtained at each step were evaluated to determine whether the assumptions supporting the model required elaboration or simplification.

The first step in the elaboration procedure was the inclusion of multiple arrival routes. There are six AFs associated with Wright-Patterson which are "fed" by several enroute low altitude airways and jet routes as illustrated in Figures 3 and 4. Each AF has associated with it a Single Standard Vectoring Route (SVR), except for ROD which has two. The SVRs are illustrated in Figure 5.

The two routes associated with ROD are required because arrivals from that AF must transition a departure corridor. If an aircraft is in the departure corridor, arrivals from ROD must maintain 9000 feet MSL until clearing the corridor. This requires the arrival aircraft to be vectored further East (ROD A) to allow room for descent. If the corridor is clear, or if coordination can be arranged with the departure controller, the arriving aircraft can be descended through the corridor and therefore can be vectored

closer to the FAF (ROD B). Personnel at Dayton Approach Control indicated the probability of being cleared through the departure corridor is .50 (13).

Aircraft arriving at the AFs are routed by an SVR to the FAF and then proceed to the runway. Arrivals at the AFs are generated by the simulation model in accordance with the distribution identified through analysis of flight progress strips.

The next factor to be incorporated into the model was differences in airspeeds. The performance characteristics of the various aircraft types to be included in the model were extracted from Jane's All the World's Aircraft (16:235-462). These characteristics were analyzed to determine natural groupings of aircraft into categories, with each category possessing three airspeeds: cruise airspeed, maneuvering airspeed, and final approach airspeed.

Five categories, "V" through "Z," were used. Category V included high performance jet fighter type aircraft (examples: F-4, T-38, F-15, F-100, etc.) and the jumbo jets (examples: C-5A, L-1011, B-747). Category W included the air-carrier type jet aircraft that are not large enough to be designated as jumbo (examples: B-707, DC-9, B-737, DC-8, C-141, KC-135). Category X included the medium size transport type aircraft (examples: C-130, Logair L-382). Category Y included the small, high performance type aircraft such as the business jet (examples:

Lear Jet, T-39, King Air, T-37, A-37, T-33, OV-10). The last category, Category Z, included the small, low speed group of aircraft (examples: Cessna 172, 180, Cherokee 140, Bonanza). The specific airspeeds corresponding to each category are listed under Data File Construction.

These airspeeds are important for the computations of the MTF between two points. The MTF varies for each category, hence a separate computation for each category was required. The computed time represents the average or expected time to fly between two points. In the simulation, however, actual times are stochastic events with as assumed normal distribution around the MTF. The computed MTF also represents the minimum time to fly between two points; that is, with no other conflicting traffic in the area, the aircraft will be expected to transit two points at the MTF. Time greater than the MTF is interpreted as delay time, and is accumulated by the GPSS computer program for use in evaluating the effectiveness of the simulation model scenario being tested.

The inclusion of Discrete Variable Delay Times (DVDT), was the next step in the elaboration process. Delays may take three forms: holding patterns, path stretching (vectoring), or speed changes. In the case of a holding pattern, an aircraft is usually committed to hold for five minutes once it enters the pattern (the time required to execute a standard holding pattern). At the minimum, an aircraft is

committed for three minutes (the time required to execute a 360 degree turn) (18:5-3 to 5-8). Because of these limitations, other delaying techniques are preferred.

"Path stretching" is a technique wherein an aircraft is directed along some route other than the SVR. These Alternate Vectoring Routes (AVR) can increase the time to fly (delay) or decrease the time to fly (advance) between two points. The seven SVRs used to route aircraft to Wright-Patterson offer very little opportunity to advance aircraft since they cover the shortest distance required to position an aircraft at the FAF. Because of this, the basic scenario is limited to delay vectors. The delay vector issued by the controller is given in anticipation of a future conflict. In this situation, the controller can only estimate the amount of delay required to bring about the desired spacing. As a result, the AVRs associated with each AF are limited to two or less depending on the AF and on airspace limitations. The AVRs are shown in Figure 10. If the delay provided by an AVR is inadequate to provide required spacing, the controller will also issue airspeed instructions.

Another delaying technique is airspeed control. By directing an increase or a decrease in airspeed, the controller can change an aircraft's arrival time at a given point within a limited range. Airspeed can be incremented or decremented over a continuous scale. In automated terminal areas, airspeed is rigidly controlled (9:3-1).

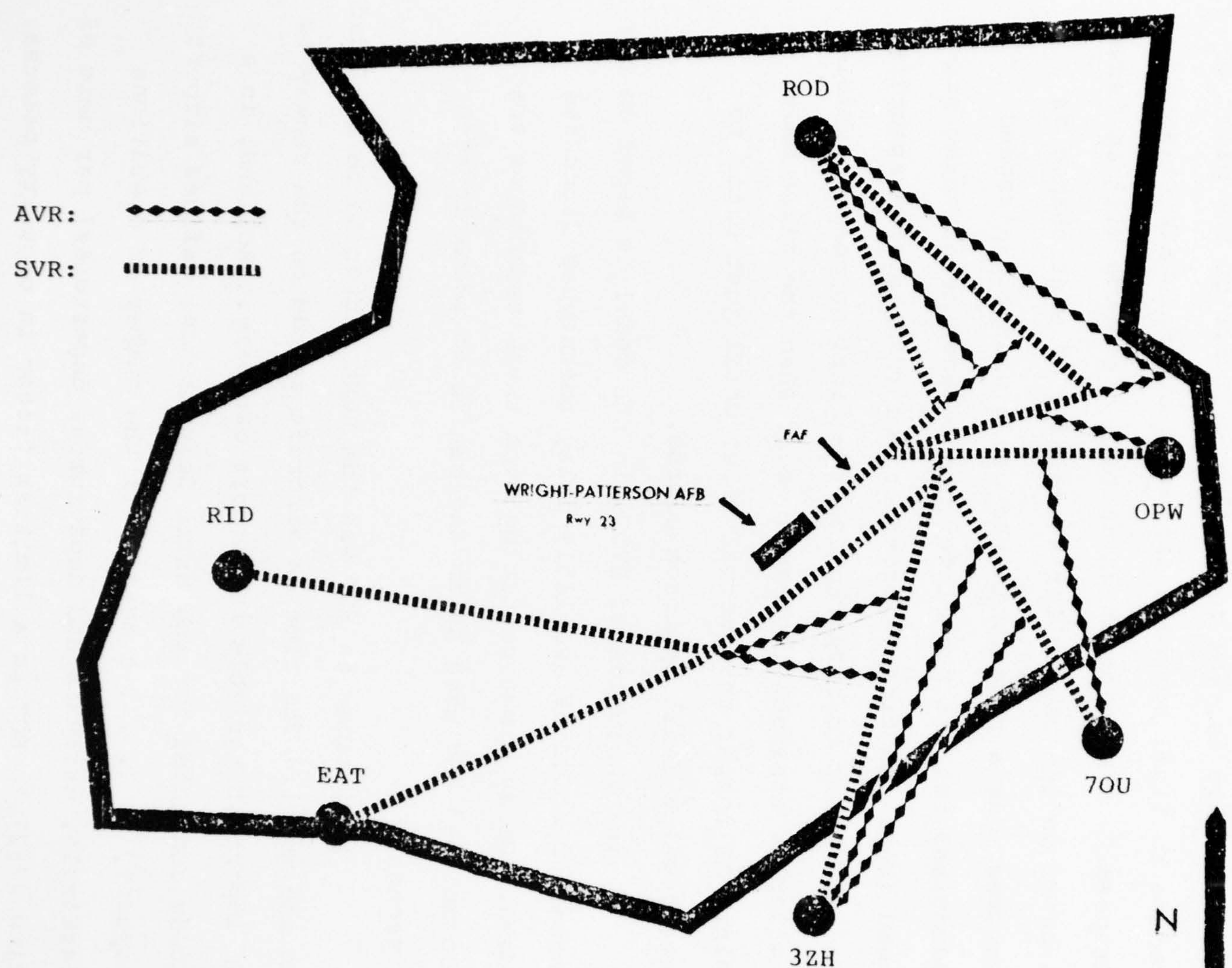


Figure 10. Alternate Vectoring Routes.

However, under normal circumstances, airspeed control is relative; that is, the controller will direct the pilot to "reduce to final approach airspeed" or "maintain present airspeed." The point at which this directive will be issued is based on the controller's estimate of what change is required. As a result, in the basic scenario airspeed reductions reflect the difference between maneuvering airspeed (MAS) and final approach speed (FAS) over a specified distance prior to intercepting the final approach course. Similarly, airspeed increases occur when the pilot maintains MAS longer than normal, i.e. until just prior to intercepting final approach course.

The inclusion of DVDTs in the model is based on the characteristics of available delay techniques discussed above. Delay times resulting from these techniques are accumulated and used as an indication of scenario effectiveness.

Variations in ROT was the next factor to be included in the model. The time an aircraft spends on the runway is an important variable in airport capacity. Holland, in a study conducted for the Mitre Corporation, defines airport capacity as ". . . a measure of the number of operations (arrivals, arrivals and departures, departures) per unit of time [7:2]." ROT is a limiting factor in capacity because, in general, simultaneous use of the runway by two or more aircraft is not permitted. Once an aircraft is authorized

the use of the runway, either for takeoff or landing, the use of the runway by other aircraft is precluded until the runway is once again unoccupied. ROT, then, determines the maximum number of operations the runway can handle per unit of time, and, consequently, places a constraint upon the ATC system capacity.

ROT is not a significant variable in light traffic situations, but its importance increases at airports where there exists a single runway, such as at Wright-Patterson AFB. In traffic situations wherein density approaches saturation, ROT becomes a critical variable due to the relationship between runway capacity and the ATC system capacity.

Holland included ROT as a subset of "Aircraft/Pilot Performance" in his schema of "Factors Affecting Airport Capacity [7:5]." The ROT for a landing aircraft begins when the aircraft crosses the runway threshold, just prior to touching down, and terminates when the aircraft has taxied physically clear of the runway. The duration of the ROT for a landing aircraft, then, is a function of numerous variables that include more than pilot or aircraft performance: aircraft speed at touch down, aircraft weight; aircraft braking capability; wind conditions on the runway (direction and velocity); runway conditions (icy, wet, dry); and the number of available exits positioned along the runway.

The ROT for departure aircraft begins when the control tower issues clearance for takeoff and ends when the

departing aircraft is airborne. Factors that affect the ROT of departure aircraft include: operating requirements of the agency controlling the use of the aircraft; aircraft performance characteristics; runway slope; meteorological conditions (wind direction and velocity, density altitude, etc.).

In order to incorporate ROT into the simulation model, data reflecting the duration of ROT by aircraft category was obtained. Observations were made of departing and landing aircraft at Wright-Patterson AFB and their respective ROTs timed. ROTs for individual aircraft were averaged to obtain ROTs by category of aircraft. The category ROTs derived through observation were used to provide general guidance only and the computed values were evaluated by tower personnel and modified as necessary to be compatible with their experience (3).

It was determined that each aircraft category has a single average ROT that applies whether an aircraft in the category is landing or departing. The ROTs for the various aircraft categories are:

1. Category V - 90 seconds
2. Category W - 120 seconds
3. Category X - 60 seconds
4. Category Y - 50 seconds
5. Category Z - 20 seconds

These times have been assigned to the various aircraft categories in the model.

The next step in the elaboration process was the inclusion of departing aircraft. Departures represent an additional demand on the runway and must be sequenced with landing traffic. Departing aircraft are generated by the simulation in accordance with the distribution derived in the data analysis. Departures normally have a lower priority for use of the runway than arrivals and are not permitted to interfere with landing traffic. However, if several aircraft are waiting for departure, departure priority may be increased. For example, if five or more aircraft are waiting for departure, the priority can be increased to the same level as arrival aircraft; if ten or more are waiting, priority can be promoted to a level higher than that of arrivals.

The Dayton ACA has four departure corridors. After takeoff, a departing aircraft is no longer considered to be a factor in the simulation, except arriving aircraft will not be permitted to transit departure corridors.

Multiple approaches constituted the next step in the elaboration procedure. Multiple approaches include aircraft executing a Missed Approach (MA) as well as training flights making a series of planned approaches and landings. An MA occurs when the pilot of an aircraft on final approach elects not to land or is denied permission to land by the

control tower. In this case the arrival aircraft is directed back to the FAF by way of an appropriate SVR. Similarly, an aircraft making multiple approaches is treated essentially the same as other traffic, the only distinction being that its SVR originates at the runway rather than at an AF. Another type of air activity that falls into the multiple approach category is the touch-an-go. A touch-and-go occurs when the aircraft lands and then takes off again without stopping. Since practice multiple approaches and touch-and-go landings do not appear on a flight progress strip, they were incorporated into the model on the basis of estimates by Dayton Approach Control Personnel (13). Missed approaches caused by traffic conflict occur whenever the simulation dictates.

The seventh step in the process of developing the simulation model was the allowance for instrument approaches other than by radar vector. In executing an instrument approach, an aircraft flies to the FAF via a published maneuvering procedure rather than an SVR. Each category of aircraft has associated with it a time that represents the MTF from an IAF to the FAF via a published approach. Arrival time at the FAF is considerably more variable for aircraft flying a published approach than for aircraft on SVRs. This increased variability could cause delays to other aircraft during high density traffic periods. The two published approaches used in the model are shown in Figures 11 and 12.

HIGH ALTITUDE
INSTRUMENT APPROACH PROCEDURE

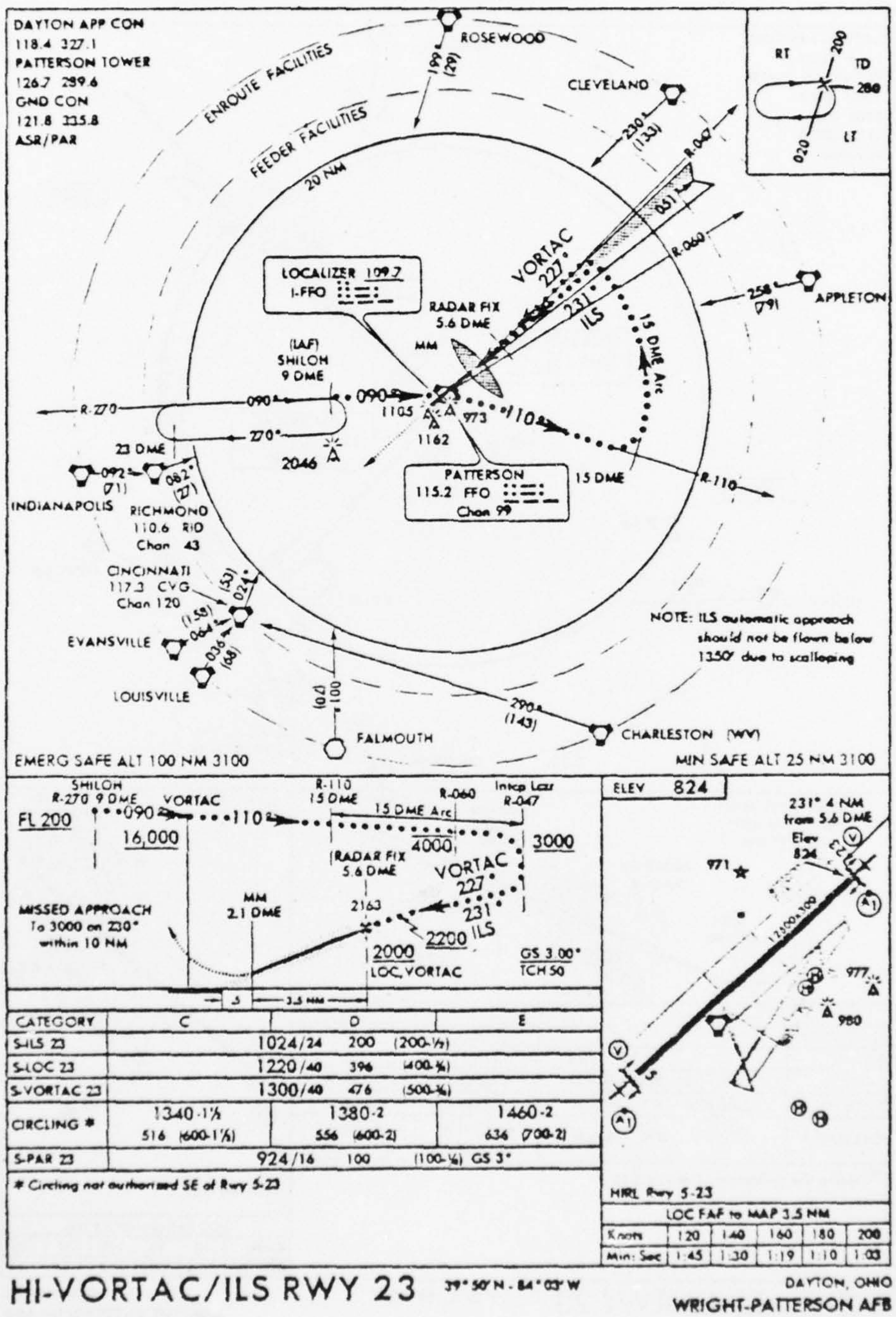


Figure 11. High Altitude Instrument Approach Procedure.

LOW ALTITUDE
INSTRUMENT APPROACH PROCEDURE

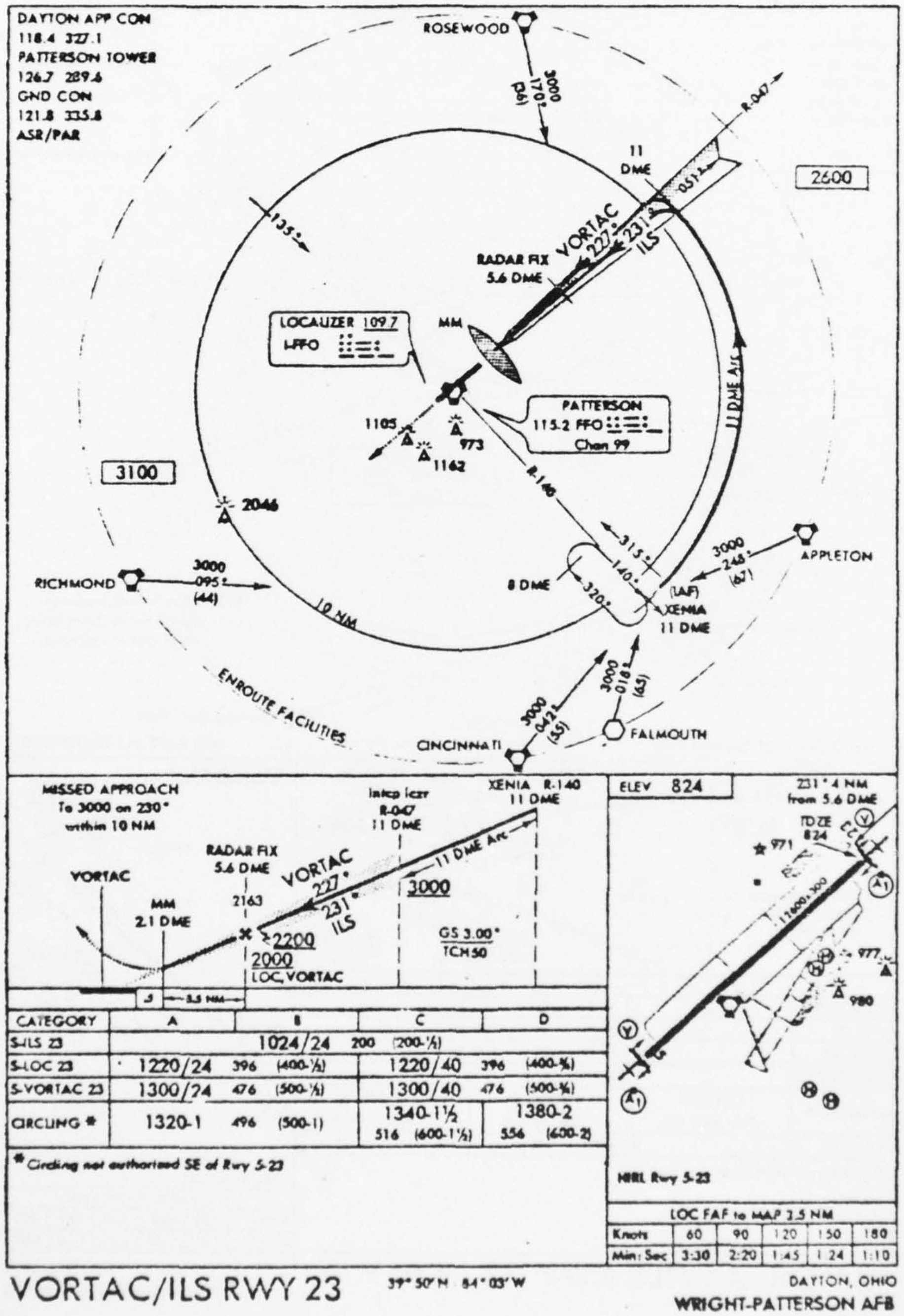


Figure 12. Low Altitude Instrument Approach Procedure.

Once cleared for an instrument approach, the pilot proceeds by his own navigation. Therefore the controller normally does not control the aircraft's arrival time through vectoring or airspeed changes. Normally, then, the aircraft will be placed in a holding pattern until the traffic in the system provides an opening. These aspects of an instrument approach have been included in the model.

Another step was the inclusion of traffic operating under VFR. Although VFR aircraft are not provided with the same control vectoring or separation as IFR aircraft, it is necessary to allow spacing so that VFR aircraft can land. In the Dayton ACA simulation model, VFR aircraft are inserted into the flow of IFR traffic on the basis of visual inspection of the final approach course by the tower controller. Once inserted, the VFR aircraft has a priority equal to IFR traffic and may cause or incur delay.

The last factor to be included in the model was differences in aircraft altitudes. Altitude is a third dimension, and its inclusion significantly complicates the model. Altitude separation allows faster aircraft to pass slower aircraft and permits simultaneous occupancy of a geographic point by more than one aircraft. The GPSS language provides simulation of these characteristics by default unless specifically precluded. Therefore, it was only necessary to provide specific altitude separation in the area between a point of common use (PCU) and the FAF

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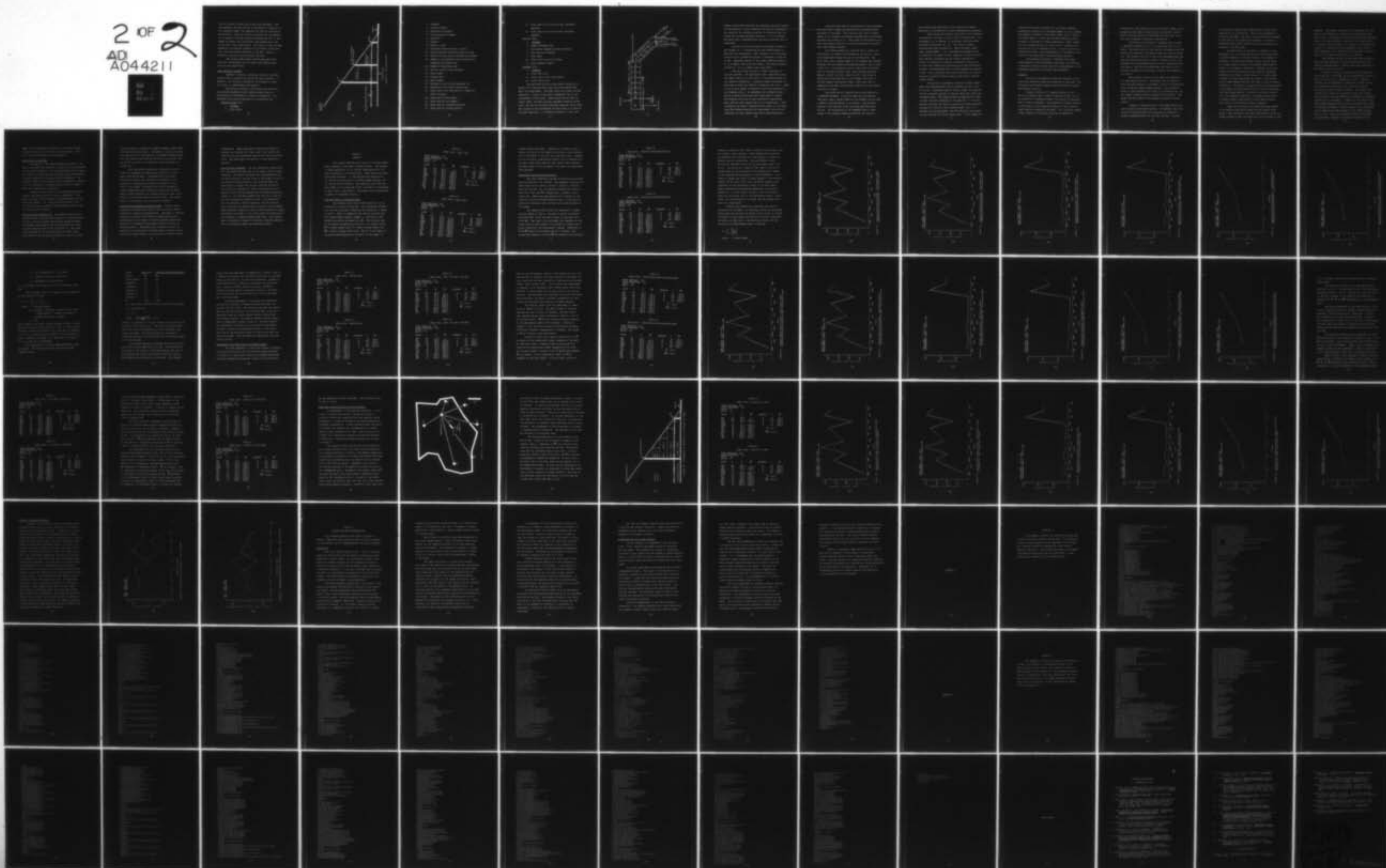

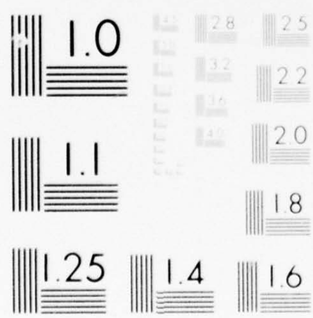

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(PCU is a point at which two or more SVRs converge). The area between a PCU and the FAF is designated a "facility" in the simulation model, and therefore can only be occupied by one aircraft. Since the traffic controller has the capability to maintain altitude separation between aircraft in the common use areas, two "facilities" were placed one on top of the other along these routes. The result is that altitude separation is provided throughout an aircraft's flight profile, from the enroute structure to the FAF. Figure 13 presents a profile of the altitudes involved.

The various complicating factors described above have been incorporated into the model using GPSS program entities and instructions.

GPSS Simulation Program

Appendix A contains a complete listing of the GPSS program used to simulate the Dayton ACA basic scenario. In addition, the following information is provided to assist the reader in understanding the program.

Transactions (aircraft) which enter the simulation are assigned parameters which reflect system status or characteristics possessed by a specific transaction. The parameters which may be assigned to a transaction are:

Floating Points (PL_i):

i	Contents
1.	Flight Rules

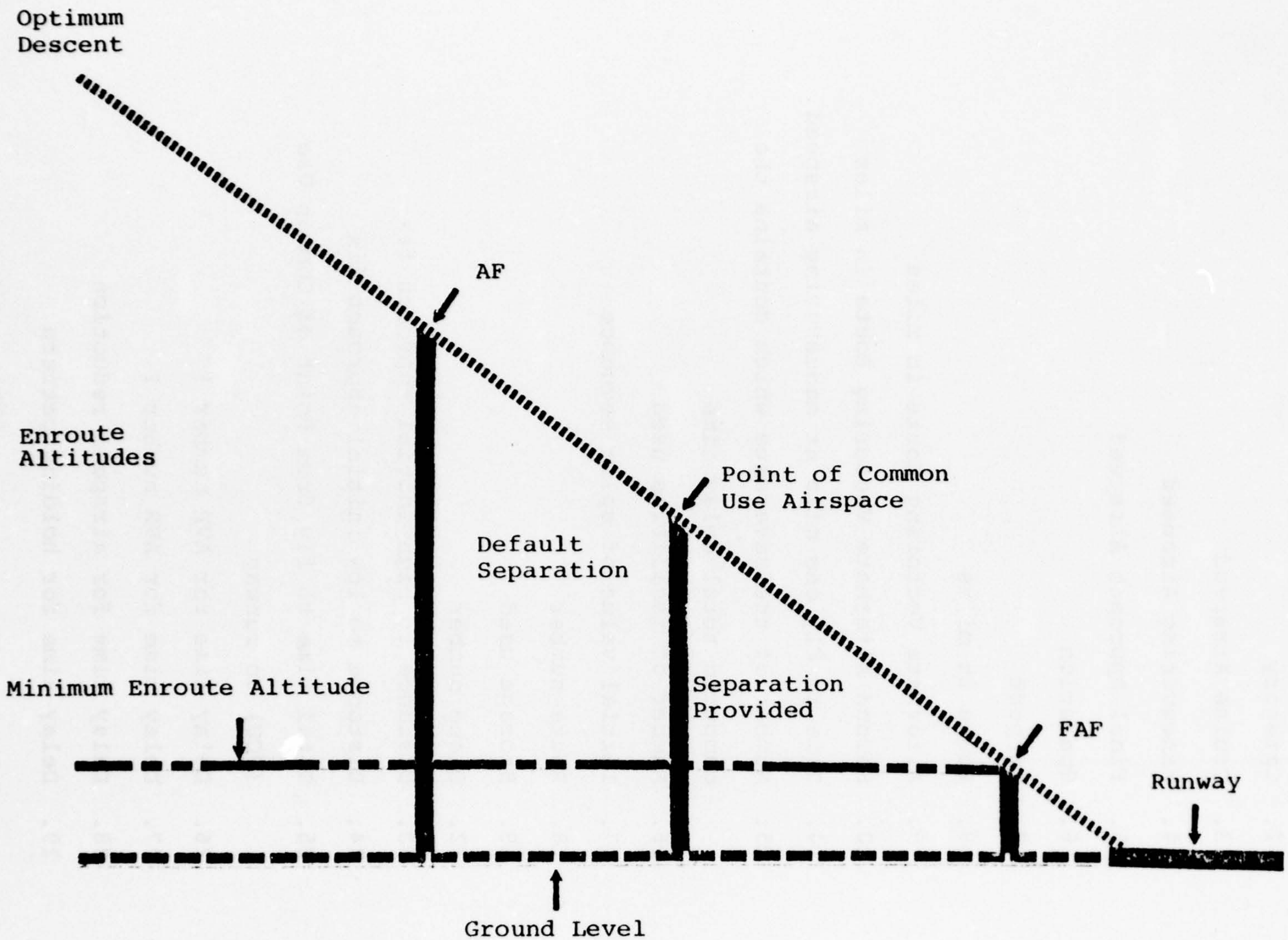

Figure 13. Altitude Profile.

2. Category
3. Cruise Airspeed
4. Maneuvering Airspeed
5. Final Approach Airspeed
6. Operation
7. Airport
8. Route in miles
9. Alternate Vectoring Route in miles
10. Second Alternate Vectoring Route in miles
14. Time to Fly one mile at manuevering airspeed
15. Number of the savevalue which contains the computed total delay time
16. Number of facilities used
17. Initial value of split sequence
18. Route number
19. Storage used
22. Queue number
23. Distance to high initial approach fix
24. Distance to low initial approach fix
25. Total time to fly from Point of Common Use (PCU) to runway
26. Delay time for AVR number 1
27. Delay time for AVR number 2
28. Delay time for airspeed reduction
29. Delay time for holding pattern

30. Total time to fly high altitude instrument approach.

31. Total time to fly low altitude instrument approach.

Halfword (PH_i):

i	Contents
2.	Runway Occupancy Time
3.	Extra delay imposed by delay technique.
4.	High facility reference
6.	Loop index
15.	Time to fly one mile on final.
17.	Split sequence number

Fullword (PF_i):

i	Contents
1.	Clock time at AF
10.	Clock time at exit from runway.
15.	Clock time at PCU.

The area from the PCU to the runway consists of a series of 19 one-mile facilities which are labeled BDF1-BDF13 and HIGH1-HIGH6. The $HIGH_i$ facilities allow altitude separation. Figure 14 provides a conceptual view of the arrangement of facilities. Other facilities include the runway (RWY), the high altitude instrument approach course (HAA), and the low altitude instrument approach course (LAA). The purpose of this arrangement of facilities is to provide aircraft separation. A transaction seizes, in turn, the

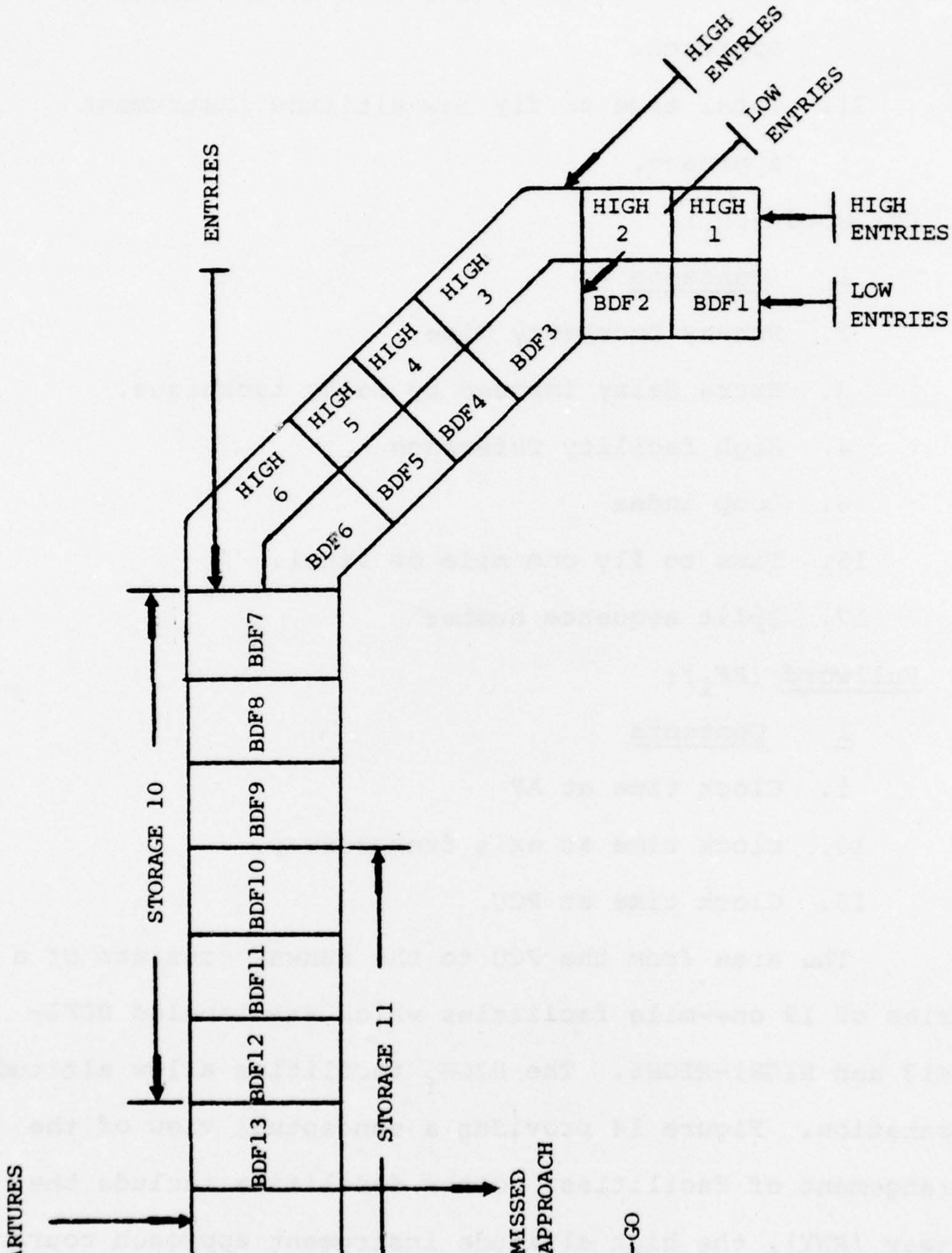

Figure 14. Arrangement of GPSS Entities.

number of facilities matching the required following distance for its category. Since a facility can only be occupied by one aircraft, the following aircraft is prevented from violating the required following distance. If it is delayed, the delay time is aggregated and the delay technique used is identified.

The PCU area also includes two storages (storage 10 and storage 11). A storage may be used simultaneously by more than one transaction. Their purpose is to allow examination of the included facilities to determine if they are in use. Departure entries to the runway examine storage 11. If it is empty, they seize the runway. VFR entries examine storage 10. If it is empty, they seize BDF12.

The split block is used to create duplicates of arriving aircraft. The duplicates enter a specified queue and remain there for a time equal to the computed delay for the "parent" transaction. A separate queue is assigned to each type of delay the "parent" transaction may incur. Usage of the various queues is computed by GPSS and presented in the standard output. To supplement the standard output, a series of matrix savevalues were established to record the category and route of each transaction experiencing delay and the total system time of all transactions. This information was used to determine which areas of the simulated ACA offered potential for improvement, and to allow comparison of total system times during experimentation.

Functions were used in the program for three purposes. The first was to create the distribution of aircraft being generated in the model. This function (FN1) uses a random number as its argument and produces exponentially distributed deviates with a mean of 1.0. This value is multiplied by the mean time between aircraft to provide exponentially distributed times between aircraft.

The second purpose of a function was to create the distribution of times to fly between any two points. This was accomplished through the use of two functions. The first (FN2) uses a random number as its argument and produces deviates that are normally distributed between 5 and -5 with a mean of 0. The resulting value is then used as the argument of a second function (FN14) which produces deviates between .90 and 1.10 with a mean of 1.00. This value is multiplied by the mean time to fly between two points to provide normally distributed times. FN15, when used in combination with FN2, gives similar results but with greater variation in times.

The third use of a function was as the modifier in a TRANSFER statement. A function used for this purpose (FN3-FN13) uses a random number as its argument and provides a symbolic program address as its output. Each program address in the function occurs with some specified probability. The transaction at the TRANSFER block is then routed to the program address provided by the function.

The probabilities specified in the functions are those described in the Analysis of Flight Progress Strips section.

Other blocks and entities were used in the simulation as required to provide a logical flow of transactions. The programming is, in general, in accordance with basic GPSS programming techniques (8, 14). One section, however, requires additional explanation. MACRO statement number eight (EIGHT: MACRO; a, b, c) provides the capability for a transaction to reduce its MTF (advance) to avoid conflict. This reduction simulates the air traffic controller's ability to recognize in advance a potential conflict and to avoid that conflict by directing one of the conflicting aircraft to maintain MAS when it *would normally be reducing* to FAS. Such a directive would have the effect of accelerating one aircraft to pass another so both could continue without delay.

The series of statements contained in MACRO number eight are referenced each time an aircraft arrives at one of the AFs. Estimated times of arrival (ETAs) are computed for the aircraft's arrival at the PCU using both normal and increased speed. The computed ETAs are compared with ETAs of other aircraft converging on the same PCU. If the comparison indicates the current aircraft will obtain adequate clearance by flying at the increased speed, then it is assigned the revised speed. The ETA reflecting the change is then recorded for future comparisons. If the comparison

indicates the current aircraft will not obtain adequate clearance by flying at the increased speed, or if it already has adequate clearance at the normal speed, then it retains its normal speed. In this case the ETA reflecting normal airspeed is recorded for future comparisons. These comparisons are accomplished on all other aircraft converging on the same PCU up to a maximum of five. It is felt that this algorithm provides a good approximation of the effect on air traffic of the controller's decision-making process.

The preceding discussion, combined with a basic understanding of GPSS programming techniques, and reference to Appendix A should provide sufficient understanding of the techniques employed in the Dayton ACA simulation.

Validity

During the development process the validity of the Dayton ACA simulation model was evaluated at each step. The evaluation was directed towards examining internal validity and external validity.

Internal validity of a research design is its ". . . ability to measure what it aims to measure [5:120]," or in the context of a simulation model, its ability to represent what it aims to represent. One measure of internal validity is the extent to which important aspects of the situation under study are covered by the model. As a practical matter, certain aspects of the Dayton ACA were excluded from

consideration (see Assumptions and Limitations) based on the assumption that their exclusion would not detract significantly from the validity of the model and that their inclusion would represent unnecessary complication.

The ability of the model to represent what it aims to represent depends heavily on the data upon which it is based. The data collection and analysis procedures described earlier were carefully developed to meet this test of validity. The aircraft activity in the fully developed model was then monitored continuously, during a variety of runs, and compared with the desired aircraft activity identified from the sample. The fully developed model was found to be an accurate reflection of the actual situation with respect to its inputs.

The internal validity of the model also depends on its consistency and logic. Consistency can be tested by using the same scenario on subsequent runs of the simulation with a different random number sequence. The stochastic events in the simulation will occur in a different way, but the overall outcome of each run should be equivalent. The Dayton ACA was tested in this manner and found to be consistent.

Changes in characteristics of the model should provide logically anticipated results. For example, the introduction of variable ROTs could logically be expected to produce increased delays for arriving aircraft. Failure

of the model to produce this expected result would raise questions as to its validity. During the development of the Dayton ACA model, the logic of the results was evaluated at each step in the elaboration procedure. Illogical or unexpected results were analyzed and corrected before progressing to the next step.

The sensitivity of the model to changes in input parameters (e.g. the characteristics of arriving aircraft) is another measure of internal validity. For example, a decrease in the mean time between arrivals should result in a proportionate increase in the delays experienced by traffic in the system. Similarly, a decrease in the percentage of arriving aircraft of one category (decreased homogeneity of traffic) should result in a proportionate increase in delays experienced by traffic in the system. Various times between arrivals were used to test the models sensitivity. The effect on system traffic was proportionate to the change in time between arrivals, and was consistent with anticipated results. Division of arriving aircraft into five categories resulted in increased average delay to system traffic, particularly to high speed aircraft. This result is as would be logically expected.

Times to fly between two points have been assumed to be normally distributed around the MTF between those points. The variance of the normal distribution was set at several values to test the sensitivity of the system to this

parameter. The effect was found to be negligible when the nominal time between air activity of 82 seconds was used. This result is attributed to the fact that the final approach course at Wright-Patterson is operating far below capacity. As a result, the occurrence of a conflict, and therefore of a delay, is a function of the randomness of air traffic. This randomness is not effected by the stochastic nature of times to fly between various points in the ACA.

The internal validity of the Dayton ACA simulation model has been adjudged to be satisfactory based on the criteria discussed above. Further tests were conducted on the models external validity.

External validity is concerned with the degree to which findings of the model can be generalized to the real world situation that it represents (5:121). External validity can be determined by comparison of model output with observed occurrences in the real world, and by evaluation of model output by experts. The output from the Dayton ACA model was evaluated by these two methods. Actual traffic flow was observed and compared to simulated traffic flow in the model. In addition, the chief of the Dayton Radar Approach Control and his assistant were asked to evaluate the model at various stages in its development and to compare the model's behavior with actual traffic flow (3, 13). Thus, the external validity of the model was confirmed. However, the ultimate validity of the

model and any solutions generated by it can only be confirmed by field test in the real world situation. Such a test is beyond the scope of this research.

Application of the Model

Validation of the computer-simulation model of the Dayton ACA marked the completion of phase one as established in the objective section. The validated model was the basic tool needed to conduct further research through experimentation with changes in ACA design and ATC procedures. The computer output of the validated model, presented in Chapter 4, is the reference or standard against which all experiments were compared for evaluation.

Analysis of the output of the validated model suggested three general areas in which to experiment. The first two areas involve changes in ATC procedures, and the third, ACA design: (1) service priority based on AFs, (2) service priority based on aircraft speed category, and (3) arrival route re-design.

Service priority based on AF. The computer output of the validated model indicated wide disparity in the utilization of AFs by arrival aircraft destined for Wright-Patterson. For example, approximately 45% of Wright-Patterson bound aircraft enter the ACA at OPW (see Figure 5). The queue discipline used in the validated model is "first come, first served," and no service priority is given to arrival

aircraft except as indicated by MACRO statement number eight (see GPSS Simulation Model). Assignment of service priority, as a function of AF, was expected to decrease average system time (the average time from the arrival of an aircraft into the system at an AF to its departure from the system at a runway exit).

This speculation represented a departure from the normal ATC procedure of handling air traffic on a first come, first served basis. Experimentation with queue discipline, however, was justified on the basis of its potential to illuminate the dynamic interaction of aircraft in the system. Following this line of reasoning, several experiments were conducted in which the validated model's queue discipline was changed from first come, first served to prioritized discipline based on AFs. The experiments, and the results, are presented in Chapter 4.

Service priority based on speed category. Aircraft speed categories is another area wherein use of priority offered potentially rewarding experimentation. Assignment of service priority to aircraft on the basis of speed category was hypothesized to be a means of reducing average system time because of the number of high speed aircraft arriving at Wright-Patterson. Experiments were conducted to test the hypothesis by altering the validated model to assign service priority by speed category in accordance with several unique

arrangements. These experiments explored the effect of changing the standard ATC "first come, first served" procedure as did the experiments dealing with service priority by AF. The experiments and results are also reported in Chapter 4.

Arrival route re-design. The last experiment accomplished with the simulation model was in the area of arrival route re-design. The design considered for experimentation was a single straight-in arrival route to the runway in lieu of the existing route structure. The validated model was restructured to permit all aircraft entering the ACA at the six AFs to converge on a single navigational fix 16 nautical miles from the approach end of Wright-Patterson's runway 23. All aircraft proceed from this fix to the runway via a straight-in approach course. This experiment did not represent a radical departure from the existing route structure (all seven arrival routes in the validated model eventually combine to form a single straight-in course as depicted in Figure 5), but it did probe the potential of ACA re-design to reduce average system time. This experiment is reported in Chapter 4 including a detailed description of the design change and experiment results.

Chapter 4

RESULTS

This chapter describes the results of several experiments conducted on the basic simulation model. The purpose of these experiments was to improve understanding of aircraft interaction in the Dayton ACA. Three groups of experiments were conducted: (1) service priority based on AF, (2) service priority based on aircraft speed category, and (3) arrival route re-design. The computer output from the basic model will be described first, followed by a discussion of each group of experiments. The chapter will conclude with a summary of experiment results.

Computer Output of the Basic Model

The computer output from a GPSS simulation is too extensive to be herein presented. The significant information has been extracted, summarized and presented in Tables 13 and 14. Table 13 summarizes the results obtained with RN1 (random number sequence number 1), and Table 14 summarizes the results obtained with RN5. The notation used in the tables is explained as follows: $\overline{D}$ = average delay, $\overline{ST}$ = average system time, $\overline{\overline{D}}$ = overall average delay, and $\overline{\overline{ST}}$ = overall average system time. MA(UP) is the number of unplanned missed approaches, and MA(P) is the number of

Table 13.

Model Data: Basic (RN1)

TOTAL ARRIVALS: 493
TOTAL DEPARTURES: 450
MA(UP): 13
MA(P): 70

ROUTE	#	$\bar{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	450	51.9	-	V	32	723.4
VFR	26	28.0	133.2	W	142	815.8
OPW	170	28.3	880.0	X	43	934.8
RODA	15	65.0	1596.0	Y	68	1203.1
RODB	19	38.3	1005.9	Z	182	1479.2
RID	7	40.9	2175.3			
7OU	62	32.5	1080.9			
3ZH	13	31.7	1468.2			
EAT	64	34.5	1764.4			
MA	83	545.0	729.7			
HAA	16	321.7	2032.9			
LAA	18	321.6	1678.4			

$\bar{\bar{D}} = 97.23$

$\overline{\overline{\overline{ST}}} = 1082.50$

Table 14.

Model Data: Basic (RN5)

TOTAL ARRIVALS: 520
TOTAL DEPARTURES: 415
MA(UP): 11
MA(P): 71

ROUTE	#	$\bar{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	415	74.0	-	V	29	773.8
VFR	45	71.8	177.9	W	130	861.5
OPW	163	26.6	892.8	X	66	927.6
RODA	18	59.2	1517.5	Y	68	1174.0
RODB	15	34.7	958.4	Z	183	1472.3
RID	6	33.3	2038.8			
7OU	74	36.8	1112.8			
3ZH	17	29.6	1407.4			
EAT	52	35.3	1783.2			
MA	82	555.3	730.8			
HAA	16	313.6	1971.1			
LAA	33	347.8	1666.5			

$\bar{\bar{D}} = 114.6$

$\overline{\overline{\overline{ST}}} = 1063.3$

planned missed approaches. Comparison of Tables 13 and 14 reveals variation in the number of aircraft in each category and in the number of aircraft that used each route. Because of this variation, experimental models will be compared with the basic model which used the same random number sequence. The basic model is the "standard," with which all experiments were compared.

Experiments Involving Priority by AF

The first experiment revised the priority of aircraft arriving from OPW, 7OU, and EAT. The geographic locations of these three AFs are shown in Figure 5, page 29. Aircraft arriving from OPW, 7OU, and EAT were assigned PR6 (priority level six), PR5, and PR4, respectively, instead of their normal PR3. These three AFs account for 79 percent of the aircraft arriving at Wright-Patterson AFB. It was anticipated that increasing their priority would reduce delays in the system.

The computer output from this experiment is summarized in Tables 15 and 16. The data in Table 15 resulted from using RN1, while the data in Table 16 resulted from using RN5. The output from this model was compared with the output from the basic model in an attempt to identify patterns, directions, and magnitudes of change. Comparison of $\bar{\bar{D}}$ and $\overline{\overline{ST}}$ reveals no consistent pattern of change. The inconsistent behavior of $\bar{\bar{D}}$ and $\overline{\overline{ST}}$ was assumed to be partially

Table 15.

Model Data: OPW=PR6/7OU=PR5/EAT=PR4(RN1)

TOTAL ARRIVALS: 497
TOTAL DEPARTURES: 436
MA(UP): 18
MA(P): 78

ROUTE	#	$\overline{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	436	57.5	-	V	42	726.3
VFR	42	79.2	183.2	W	144	793.1
OPW	147	26.8	887.8	X	32	978.5
RODA	17	54.5	1394.0	Y	63	1272.1
RODB	24	42.0	974.0	Z	174	1410.2
RID	10	45.1	2064.2			
7OU	68	35.8	1099.5	$\overline{\overline{D}} = 107.6$		
3ZH	14	37.0	1539.3			
EAT	55	37.3	1718.5	$\overline{\overline{ST}} = 1024.6$		
MA	96	556.0	720.8			
HAA	7	300.0	1847.9			
LAA	17	307.0	1784.2			

Table 16.

Model Data: OPW=PR6/7OU=PR5/EAT=PR4(RN5)

TOTAL ARRIVALS: 497
TOTAL DEPARTURES: 432
MA(UP): 19
MA(P): 66

ROUTE	#	$\overline{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	432	58.4	-	V	38	787.4
VFR	28	29.8	135.6	W	155	833.1
OPW	175	27.4	896.3	X	35	1022.3
RODA	19	63.8	1530.1	Y	56	1284.6
RODB	19	60.1	1106.9	Z	185	1400.3
RID	7	48.4	2067.4			
7OU	57	35.0	1101.2	$\overline{\overline{D}} = 106.4$		
3ZH	14	34.5	1482.8			
EAT	54	34.4	1705.6	$\overline{\overline{ST}} = 1065.6$		
MA	85	560.9	734.5			
HAA	16	314.3	1835.1			
LAA	23	357.3	1607.7			

caused by changes in the volume of traffic on each route, and the volume in each category. These changes were caused by the PRIORITY block inserted into the program to achieve the desired priority alterations. The new PRIORITY blocks re-initiate the GPSS scan of the current events chain (8:3-21/22). The result is a change in the order of arrival of transactions at various blocks in the program and a change in the characteristics assigned to each transaction. In an effort to reduce the effect of these changes in the volume of traffic, $\overline{ST}$ by route, $\overline{D}$ by route, and $\overline{ST}$ by category were compared with the counterpart values in the basic model. These comparisons are portrayed graphically in Figures 15 through 20. In each figure, the *solid line* is the basic model and the dashed line is the experimental model. Again, there is no strong pattern of change, and the changes that occur are inconsistent.

Analysis was conducted to determine the relative efficiency of the model. An efficiency factor was developed which takes into account the change in $\overline{D}$ by route, by volume of traffic on each route, and by mix of aircraft categories of traffic on each route. The efficiency factor was computed for each experimental model as follows:

$$E = \sum_{i=1}^{12} \left[\frac{d_i f_i}{a_i} \right]$$

where: i = Route number

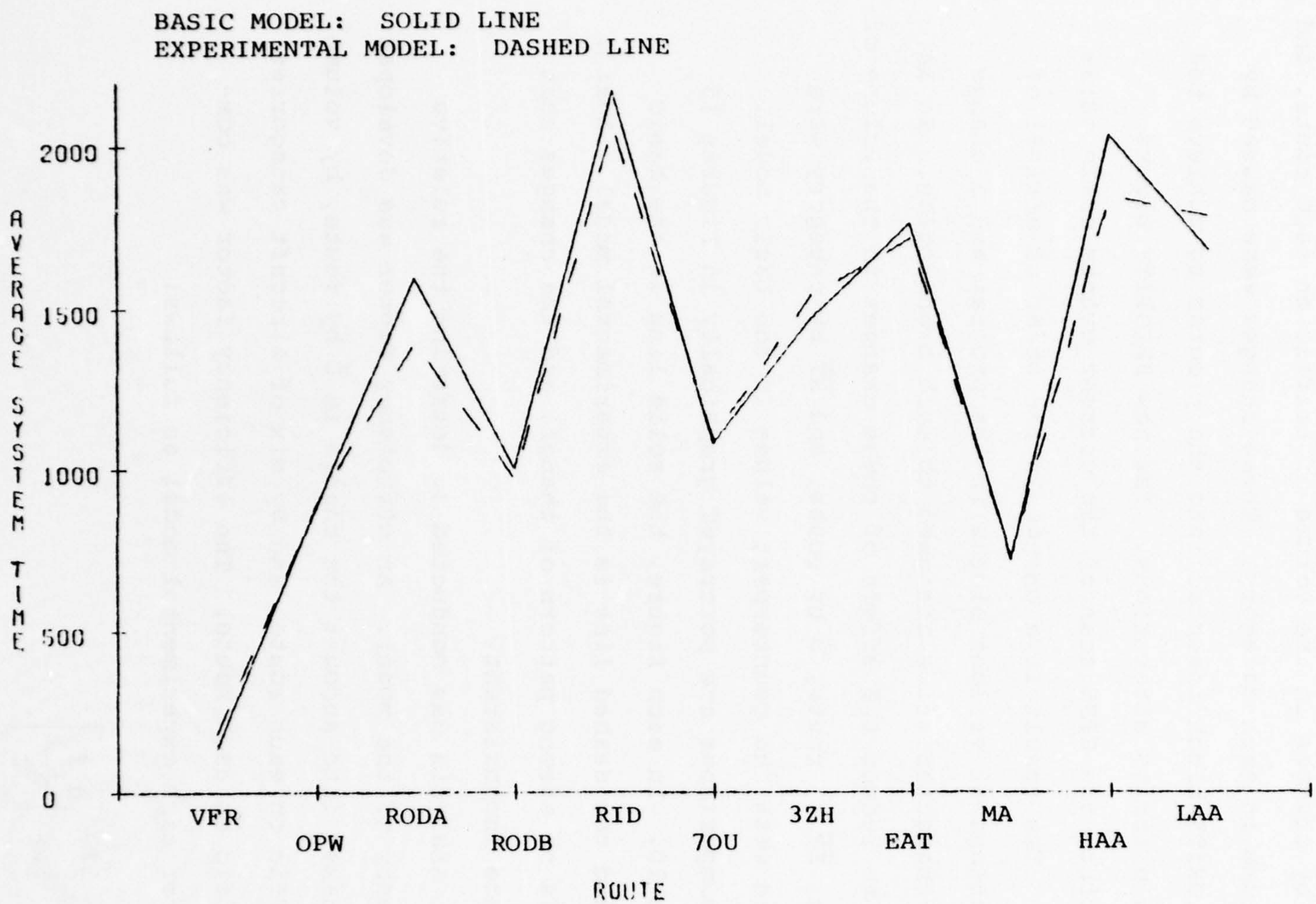

Figure 15: Average System Time by Route - Experimental Model (OPW=PR6/7OU=PR5/EAT=PR4-RN1) versus Basic Model

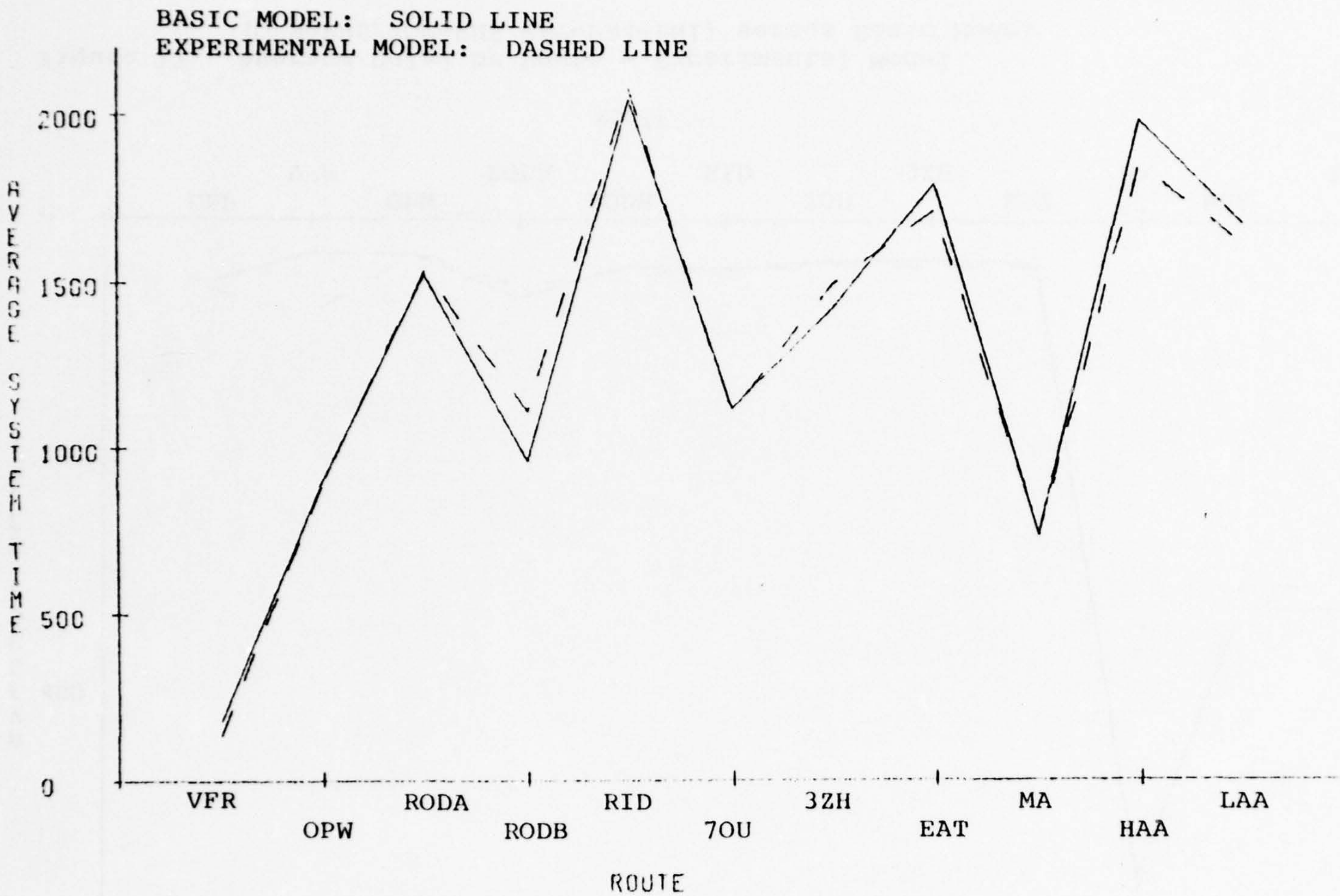

Figure 16. Average System Time by Route - Experimental Model (OPW=PR6/7OU=PR5/EAT=PR4-RN5) versus Basic Model

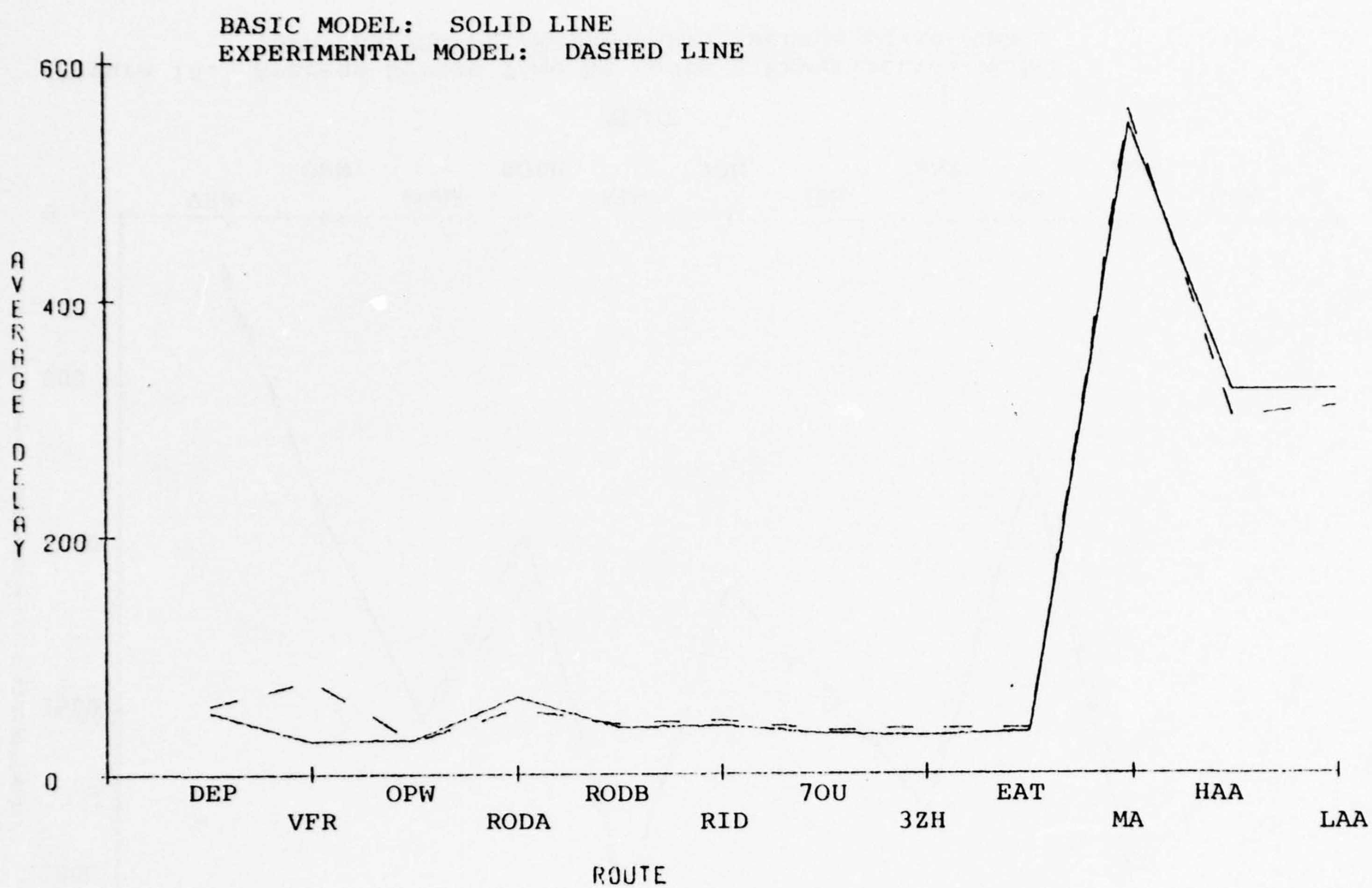

Figure 17. Average Delay by Route - Experimental Model (OPW=PR6/7OU=PR5/EAT=PR4-RN1) versus Basic Model

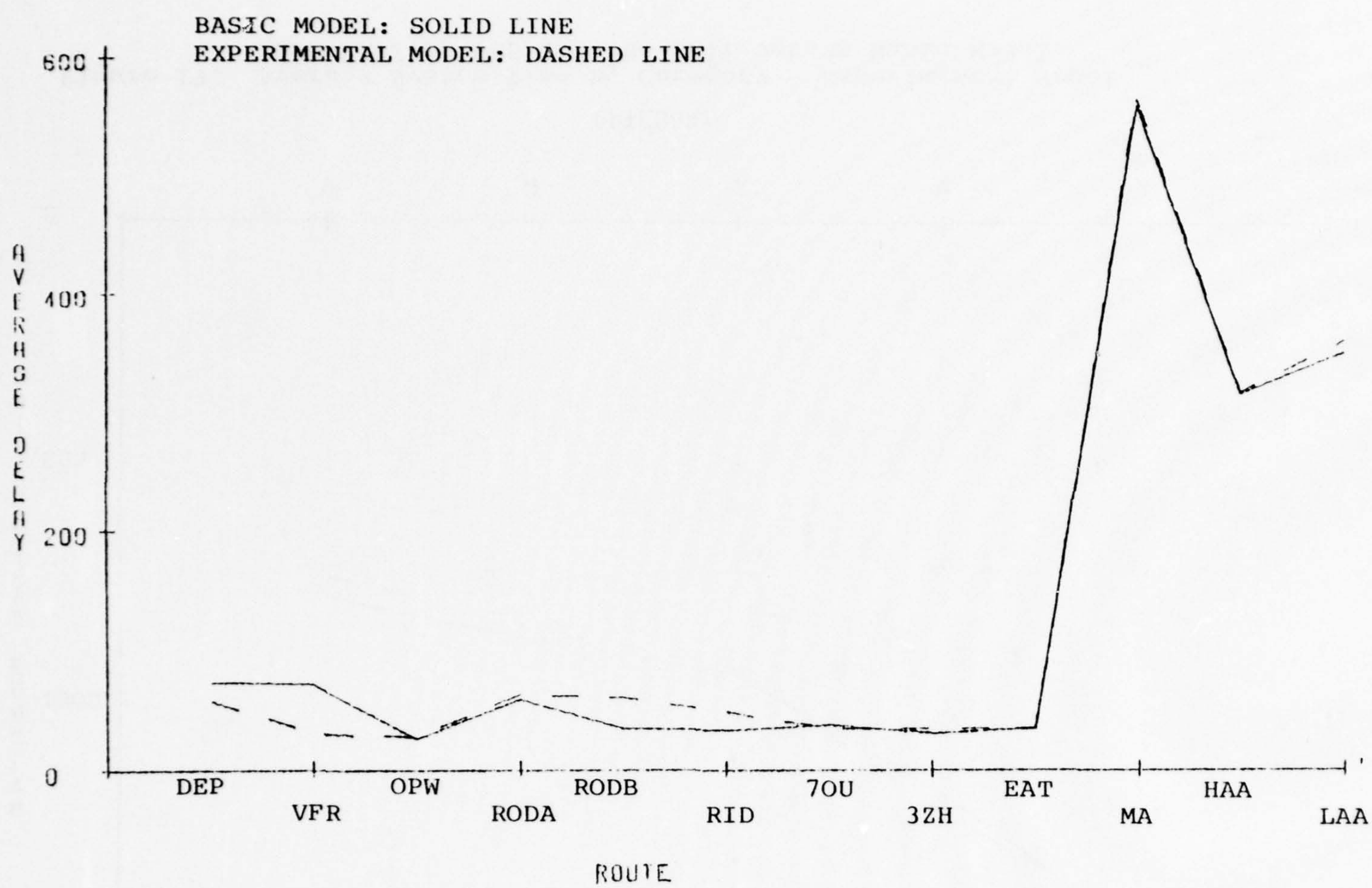

Figure 18. Average Delay by Route - Experimental Model (OPW=PR6/7OU=PR5/EAT=PR4-RN5) versus Basic Model

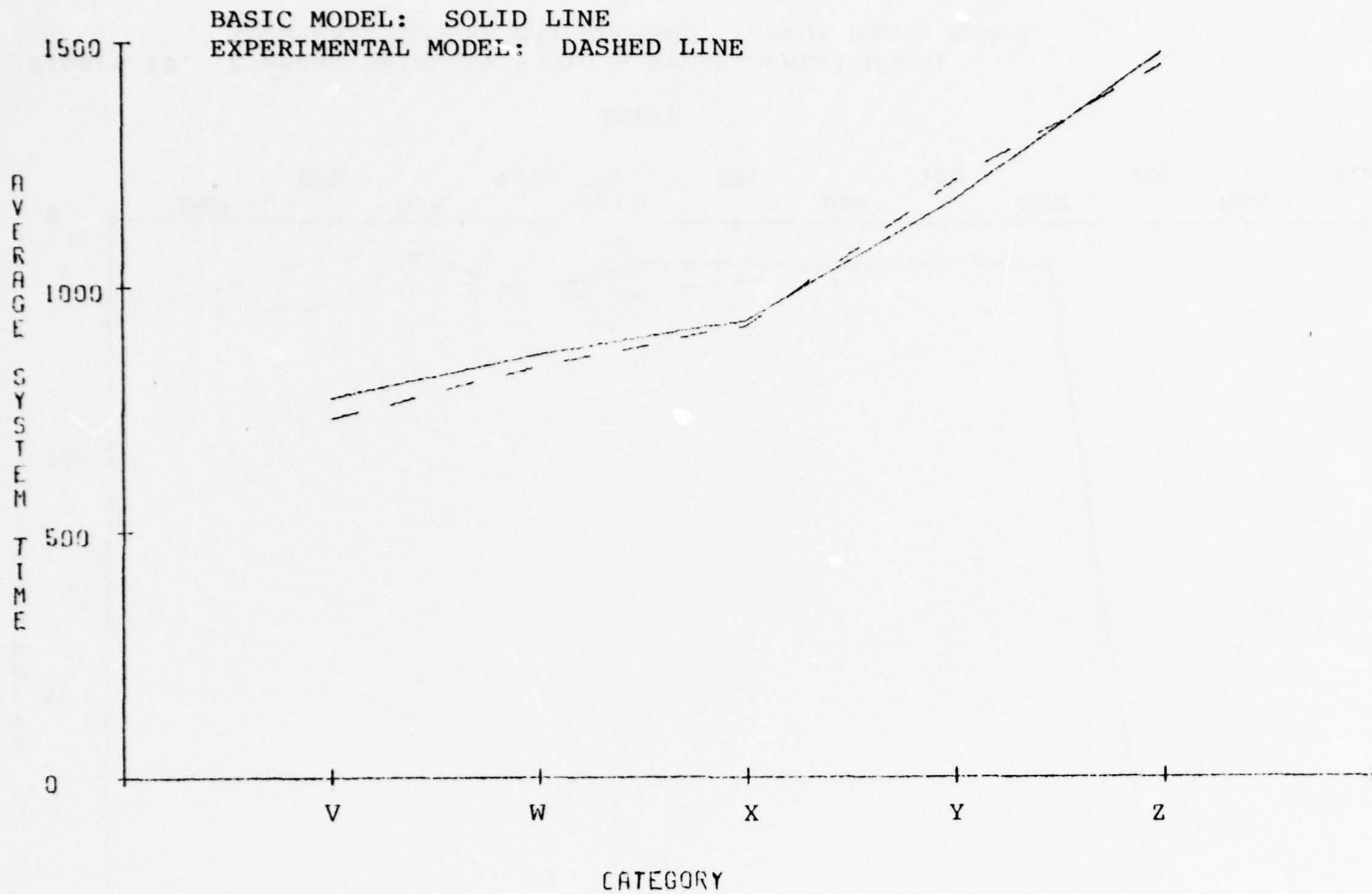

Figure 19. Average System Time by Category - Experimental Model (OPW=PR6/7OU=PR5/EAT=PR4-RN1) versus Basic Model

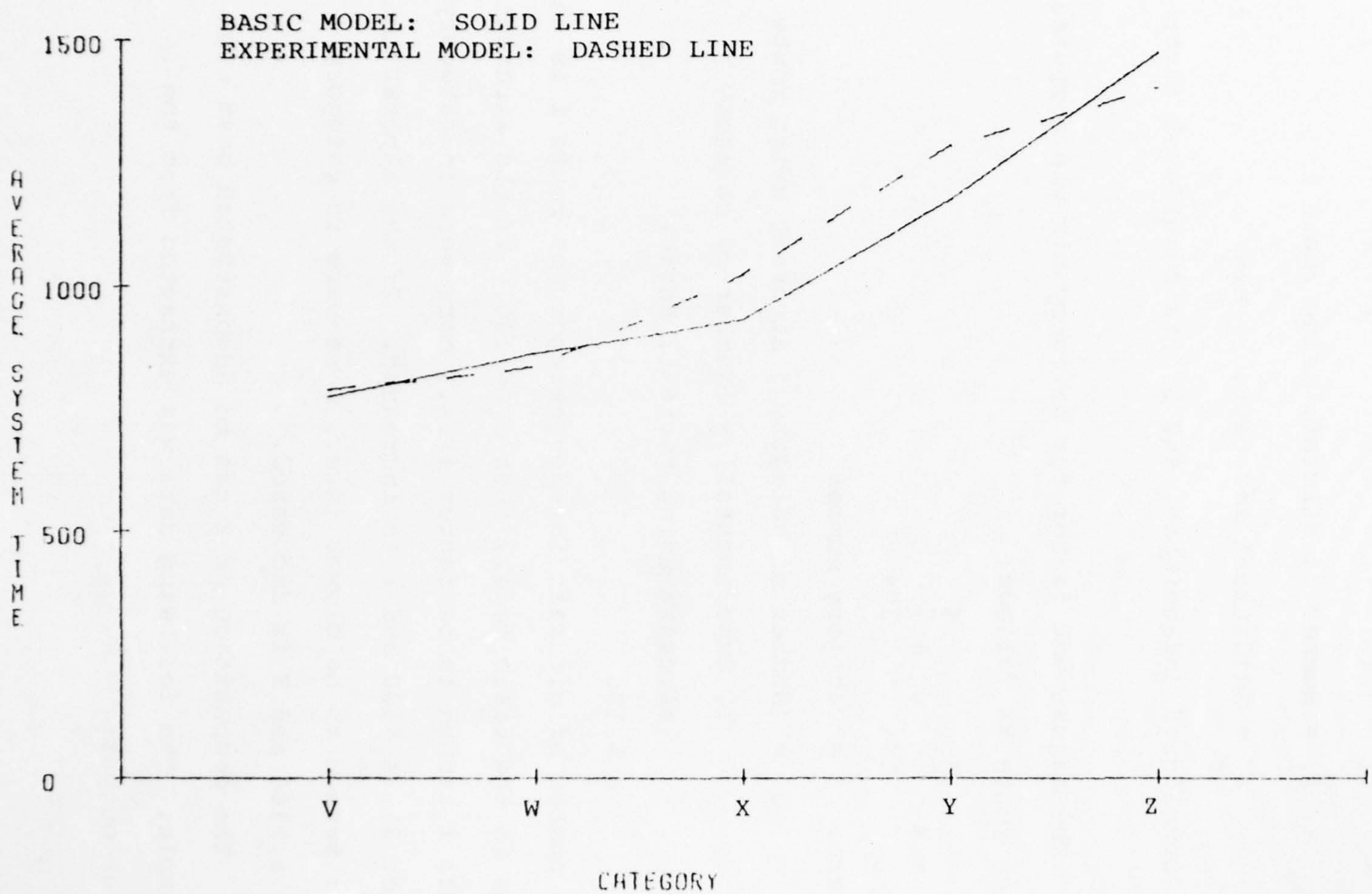

Figure 20. Average System Time by Category - Experimental Model (OPW=PR6/7OU=PR5/EAT=PR4-RN5) versus Basic Model

$d_i = (\bar{D}_i$, Experimental$) - (\bar{D}_i$, Basic$)$

f_i = Number of aircraft using route i

a_i = Adjustment for category mix

$E>0$ is considered unfavorable, and $E<0$ is considered favorable.

The adjustment factor for category mix was computed for each route as follows:

$$a_i = k - \sum_{j=i}^{3} c_j + \sum_{j=4}^{5} c_j$$

where: j = Category number

c_j = (Number of category j aircraft using route i, Experimental) - (Number of category j aircraft using route i, Basic)

$k = 100$

If the number of aircraft in each category on route i is the same as in the basic model, then $a_i = 100$. If the aircraft on route i tended to be faster (i.e., more were in category 1, 2, or 3), $a_i<100$ and E is increased. If the aircraft on route i tended to be slower (i.e., more were in category 4 or 5), $a_i>100$ and E is decreased.

The computation of E can be demonstrated best with an example. The following data was extracted from the computer output:

Model:	Basic(RN1)	OPW=PR6/70U=PR5/EAT=PR4(RN1)
Route:	OPW	OPW
Total Number:	170	147
Category 1:	10	17
Category 2:	60	50
Category 3:	15	8
Category 4:	15	12
Category 5:	75	60
$\overline{D}$:	28.3	26.8

$a_1 = 100-[(10-17)+(60-50)+(15-8)]+[(15-12)+(75-60)]=108$

$d_1 = 26.8-28.3=-1.5$

$f_1 = 170$

$$E(OPW) = \left[\frac{(-1.5)(170)}{108}\right] = -2.36$$

E(Route) is computed in a similar manner for each route, and the sum of these values is E. The value of the efficiency factor for the first experiment is +61.03 using RN1, and -64.84 using RN5. The efficiency factor indicates an unfavorable change in the first case, but a favorable change in the second case.

The second experiment increased the priority of aircraft arriving from OPW from PR3 to PR5. OPW accounts for 45 percent of the arrivals to Wright-Patterson AFB, and it was believed that giving these aircraft service priority would improve the efficiency of the system. The computer

output from this experiment is summarized in Tables 17 and 18. A comparative analysis was conducted on this data in the same manner as described for the previous experiment. Changes in $\overline{D}$ and $\overline{ST}$ were again inconsistent and showed no obvious pattern. Analysis of $\overline{ST}$ by route, $\overline{D}$ by route, and $\overline{ST}$ by category provided equally inconsistent results. The value of the efficiency factor was found to be +61.73 using RN1 and -86.79 using RN5.

The final experiment in this group was effected by revising the priority of aircraft arriving from OPW, 7OU, and EAT from PR3 to PR5. The rationale used for this experiment was that the hierarchy of priorities used in the first experiment might be causing complex traffic interactions, thus creating delays. The computer output from this experiment is summarized in Tables 19 and 20. The same analysis was conducted on this data as on the previous experiments. As before, there is no discernable pattern in the output. The value of the efficiency factor is +88.44 using RN1, and -46.09 using RN5. This concluded the experiments involving priority by AF.

Experiments Involving Priority by Speed Category

The first experiment in this group tested a hierarchy of service priority for the five aircraft speed categories (V through Z). The aircraft types and airspeeds associated with each category are presented in Data File Construction,

Table 17.

Model Data: OPW=PR5(RN1)

TOTAL ARRIVALS: 505
TOTAL DEPARTURES: 437
MA(UP): 11
MA(P): 74

ROUTE	#	$\overline{D}$	$\overline{ST}$
DEP	437	61.5	-
VFR	42	57.6	162.6
OPW	172	26.7	902.4
RODA	20	55.2	1412.4
RODB	19	42.8	1018.3
RID	11	45.7	2289.4
7OU	64	36.6	1106.9
3ZH	13	28.7	1434.6
EAT	41	35.3	1684.4
MA	85	550.8	737.2
HAA	10	354.3	2140.4
LAA	28	320.6	1652.6

CATEGORY	#	$\overline{ST}$
V	30	732.1
W	143	854.3
X	47	899.1
Y	74	1168.6
Z	179	1405.1

$\overline{\overline{D}} = 105.9$

$\overline{\overline{ST}} = 1037.4$

Table 18.

Model Data: OPW=PR5(RN5)

TOTAL ARRIVALS: 501
TOTAL DEPARTURES: 439
MA(UP): 16
MA(P): 75

ROUTE	#	$\overline{D}$	$\overline{ST}$
DEP	439	60.9	-
VFR	31	23.8	129.0
OPW	166	26.9	877.3
RODA	22	59.1	1502.2
RODB	21	41.3	989.2
RID	9	40.0	2014.6
7OU	58	34.5	1101.3
3ZH	15	40.0	1405.5
EAT	55	36.7	1788.8
MA	91	574.9	744.8
HAA	9	384.4	2202.8
LAA	24	346.2	1678.1

CATEGORY	#	$\overline{ST}$
V	35	720.4
W	135	802.1
X	50	976.4
Y	68	1171.8
Z	182	1465.9

$\overline{\overline{D}} = 109.8$

$\overline{\overline{ST}} = 1063.5$

Table 19.

Model Data: OPW, 7OU, EAT = PR5(RN1)

TOTAL ARRIVALS: 541
TOTAL DEPARTURES: 420
MA(UP): 18
MA(P): 93

ROUTE	#	$\overline{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	420	58.6	-	V	44	729.3
VFR	46	96.6	201.2	W	137	796.8
OPW	161	27.7	883.3	X	56	872.7
RODA	15	61.3	1558.7	Y	68	1169.1
RODB	30	48.4	1033.9	Z	191	1454.3
RID	10	37.2	2015.6			
7OU	73	37.3	1145.8	$\overline{\overline{D}}$ = 117.9		
3ZH	13	53.6	1608.5			
EAT	53	33.9	1759.5	$\overline{\overline{\overline{ST}}}$ = 1028.9		
MA	111	568.0	738.3			
HAA	9	300.0	1840.7			
LAA	20	308.2	1675.9			

Table 20.

Model Data: OPW, 7OU, EAT = PR5(RN5)

TOTAL ARRIVALS: 510
TOTAL DEPARTURES: 412
MA(UP): 21
MA(P): 72

ROUTE	#	$\overline{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	412	51.8	-	V	49	677.7
VFR	21	176.8	281.8	W	126	801.7
OPW	181	28.6	883.9	X	71	848.1
RODA	22	62.8	1532.8	Y	49	1324.8
RODB	20	48.1	1040.4	Z	194	1442.8
RID	6	39.1	1894.3			
7OU	70	32.5	1100.1	$\overline{\overline{D}}$ = 105.0		
3ZH	15	35.1	1361.7			
EAT	53	35.4	1847.6	$\overline{\overline{\overline{ST}}}$ = 1069.0		
MA	93	544.5	716.0			
HAA	9	309.1	1898.6			
LAA	20	292.9	1715.7			

page 34, and Development, page 64. The highest priority, PR7, was assigned to category V aircraft and each of the remaining four categories received successively lower service priorities (W=PR6, X=PR5, Y=PR4, Z=PR3). The hierarchy was established in response to the hypothesis that average system time would decrease if higher speed aircraft were always given service priority. The experiment was conducted to test the hypothesis and to ascertain the extent of traffic interaction by identifying the magnitude and direction of change patterns.

The computer output from this experiment is summarized in Tables 21 and 22. The data in Table 21 resulted from RN1 and that in Table 22 from RN5. The data tables were compared against their counterparts (Tables 13 and 14) of the basic model. $\overline{\overline{ST}}$ for all aircraft decreased somewhat in the experimental model but $\overline{\overline{D}}$ increased. Category W, Category X, and Category Z aircraft experienced a decrease in $\overline{ST}$ while Category Y experienced an increase. The change in $\overline{ST}$ for Category V was inconsistent.

Figures 21 and 22 are a graphic presentation of $\overline{ST}$ by route, for the experimental model, compared to the same for the basic model. Figures 23 and 24 illustrate $\overline{D}$ by route for the experimental model, compared to $\overline{D}$ by route for the basic model. Figures 25 and 26 graphically compare $\overline{ST}$ by category, for the experimental model, to $\overline{ST}$ by category for the basic model. In each figure, the solid

Table 21.

Model Data: V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3(RN1)

TOTAL ARRIVALS: 504
TOTAL DEPARTURES: 435
MA(UP): 20
MA(P): 86

ROUTE	#	$\overline{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	435	56.2	-	V	43	723.8
VFR	31	54.5	161.3	W	140	778.2
OPW	149	29.4	901.6	X	60	908.0
RODA	17	50.9	1311.4	Y	63	1212.4
RODB	29	36.5	892.9	Z	167	1437.2
RID	11	40.4	2108.2			
7OU	61	31.7	1061.5		$\overline{\overline{D}}$ = 109.9	
3ZH	12	32.9	1435.8			
EAT	54	31.4	1725.5		$\overline{\overline{ST}}$ = 1023.7	
MA	106	521.9	697.7			
HAA	7	342.9	1993.0			
LAA	28	307.5	1530.8			

Table 22.

Model Data: V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3(RN5)

TOTAL ARRIVALS: 490
TOTAL DEPARTURES: 406
MA(UP): 31
MA(P): 66

ROUTE	#	$\overline{D}$	$\overline{ST}$	CATEGORY	#	$\overline{ST}$
DEP	406	76.5	-	V	40	729.5
VFR	33	63.4	167.9	W	131	835.8
OPW	170	30.6	917.2	X	53	918.3
RODA	17	53.6	1373.2	Y	58	1211.7
RODB	17	55.8	1114.8	Z	208	1445.7
RID	9	42.3	2111.6			
7OU	70	35.8	1113.5		$\overline{\overline{D}}$ = 128.5	
3ZH	13	31.2	1477.9			
EAT	60	38.7	1890.7		$\overline{\overline{ST}}$ = 1150.7	
MA	97	581.5	754.9			
HAA	12	279.8	1553.5			
LAA	24	399.5	1530.6			

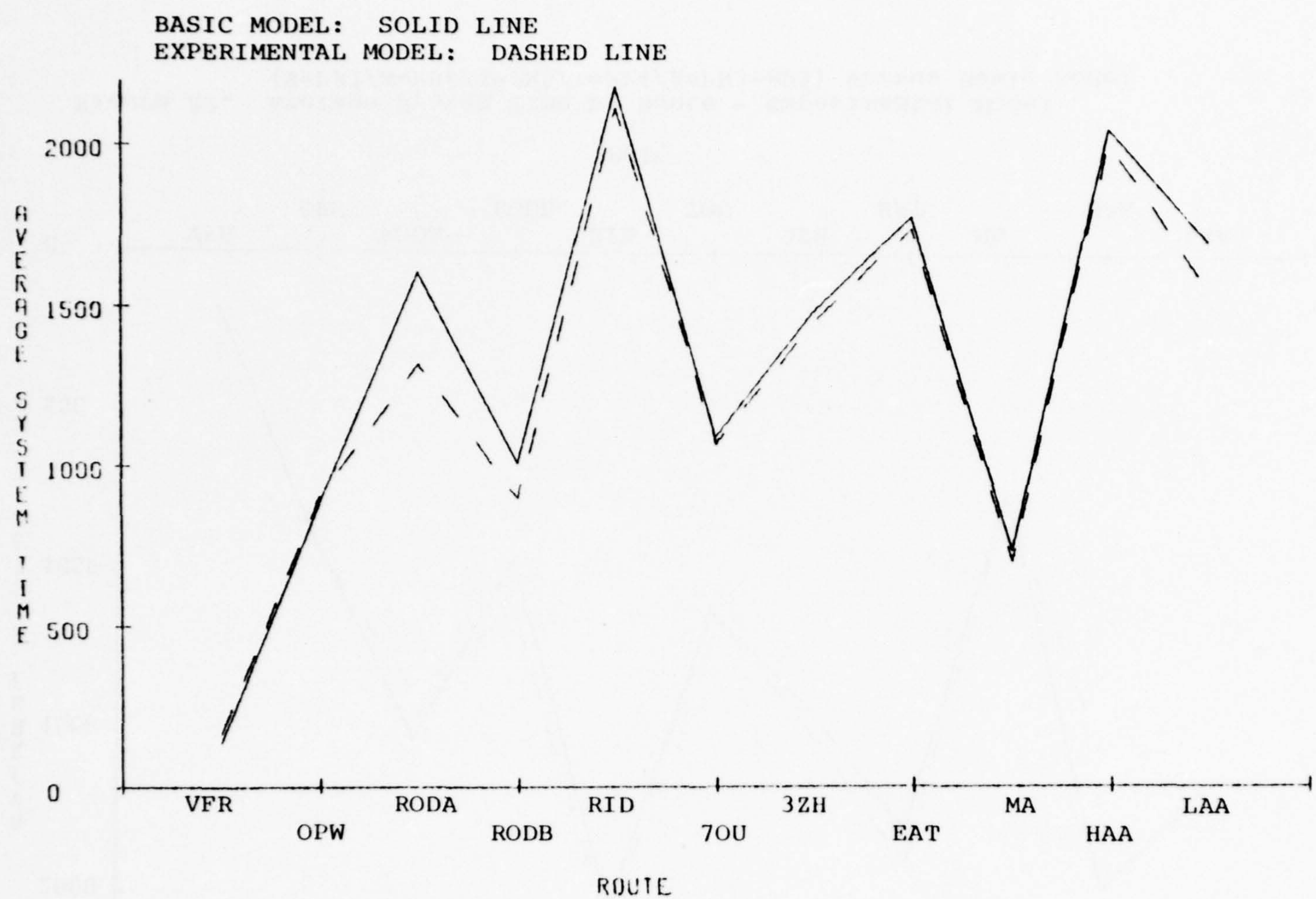

Figure 21. Average System Time by Route - Experimental Model (V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3-RN1) versus Basic Model

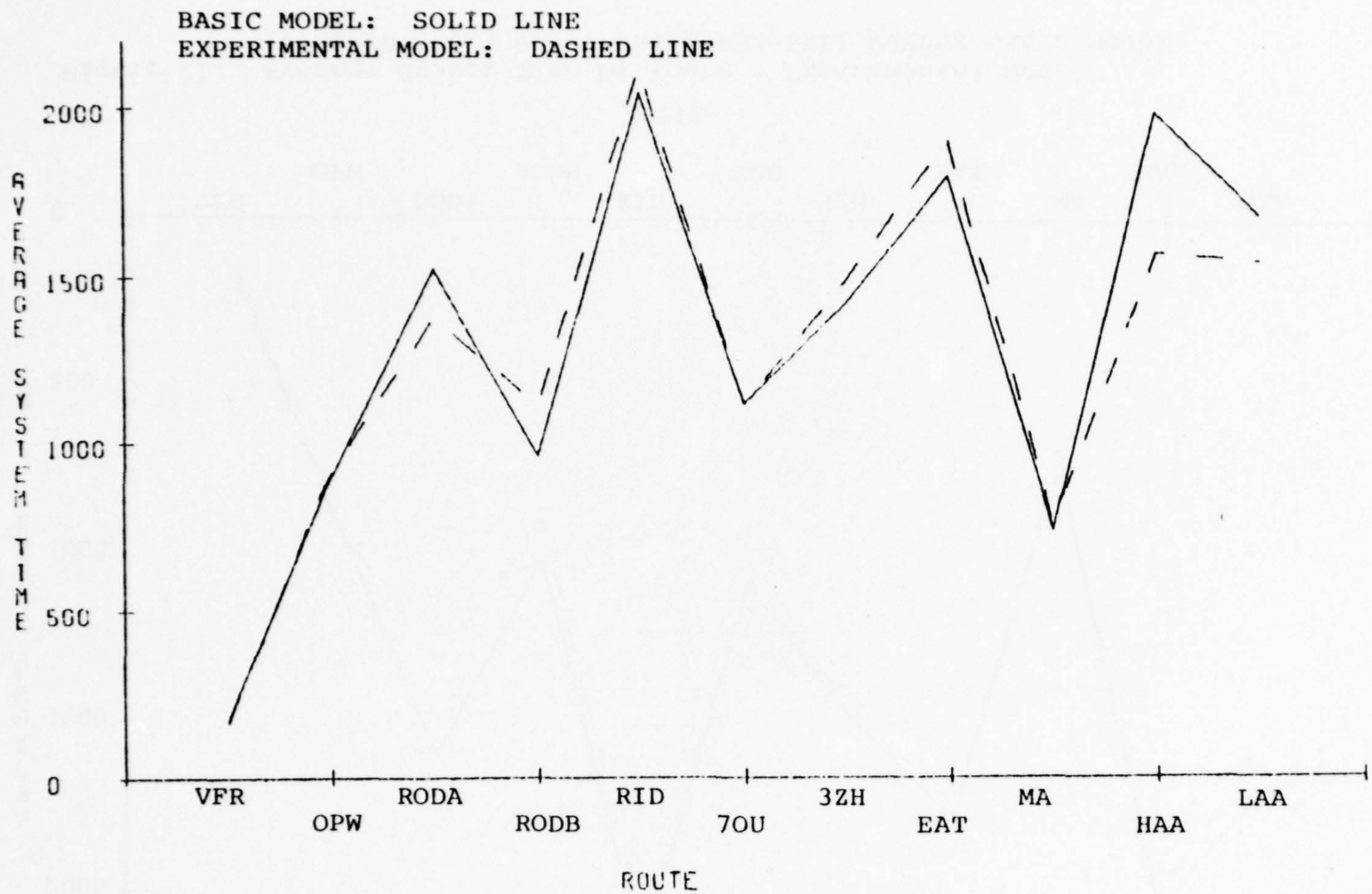

Figure 22. Average System Time by Route - Experimental Model (V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3-RN5) versus Basic Model

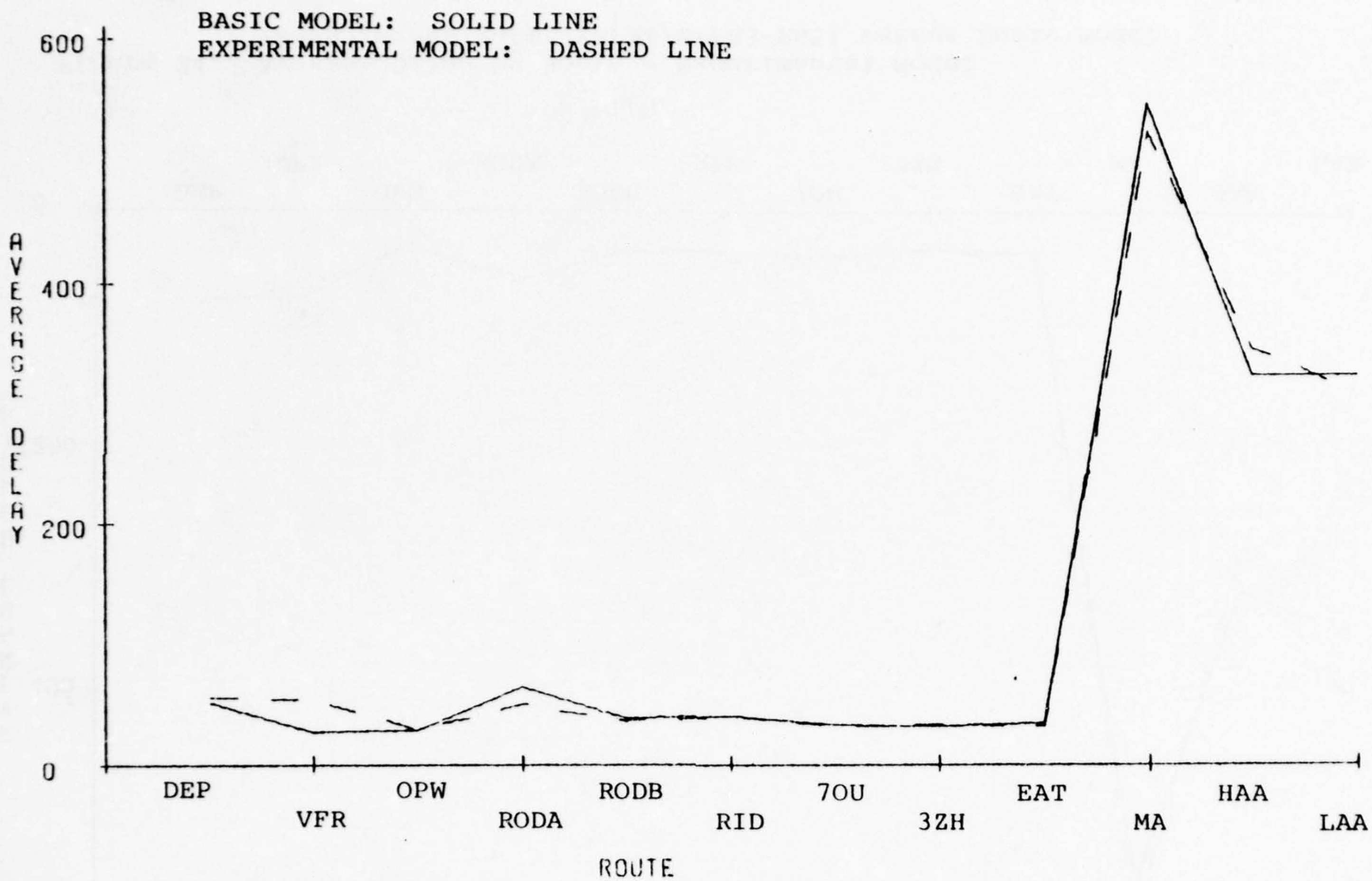

Figure 23. Average Delay by Route - Experimental Model (V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3-RN1) versus Basic Model

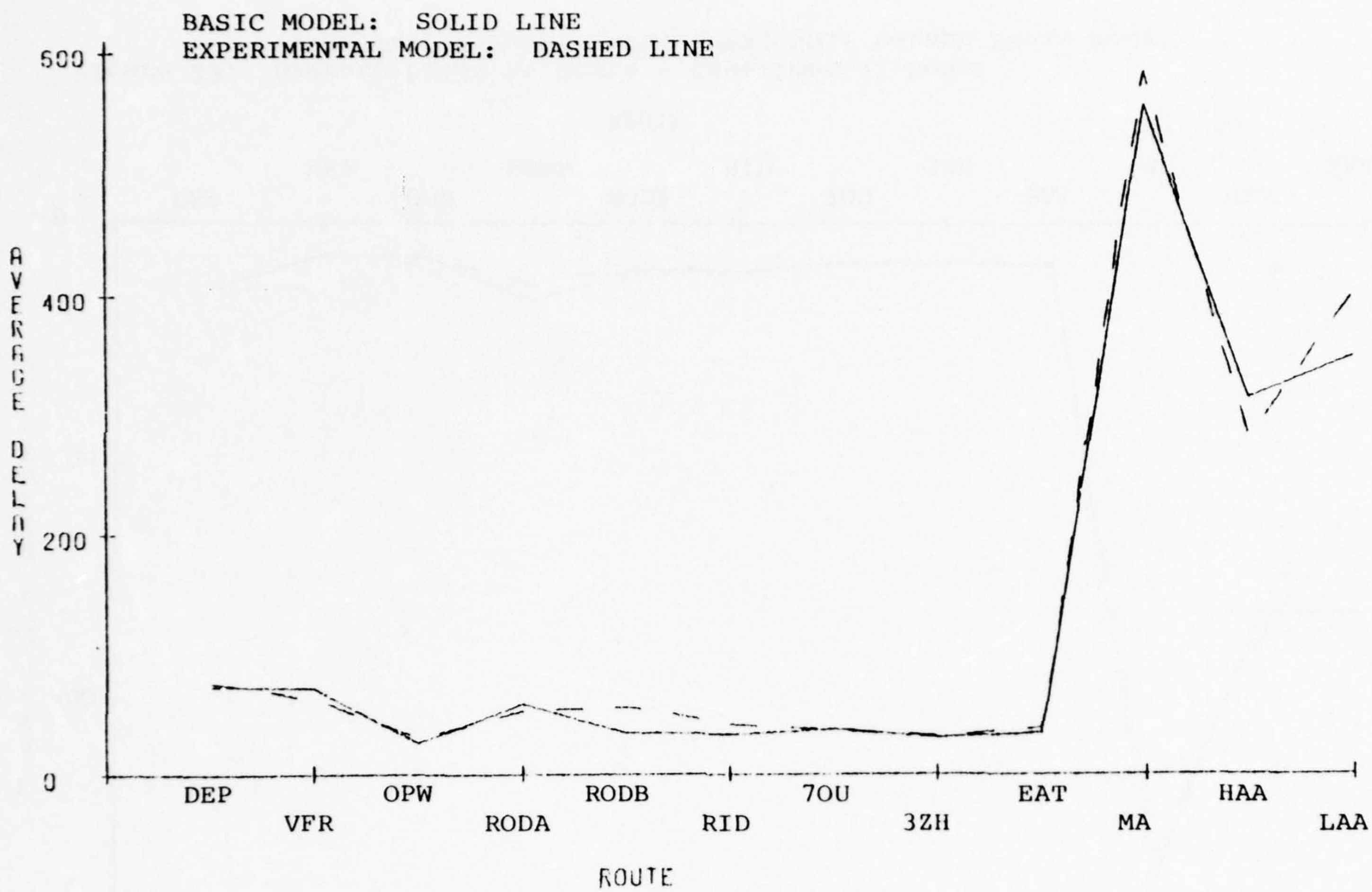

Figure 24. Average Delay by Route - Experimental Model (V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3-RN5) versus Basic Model

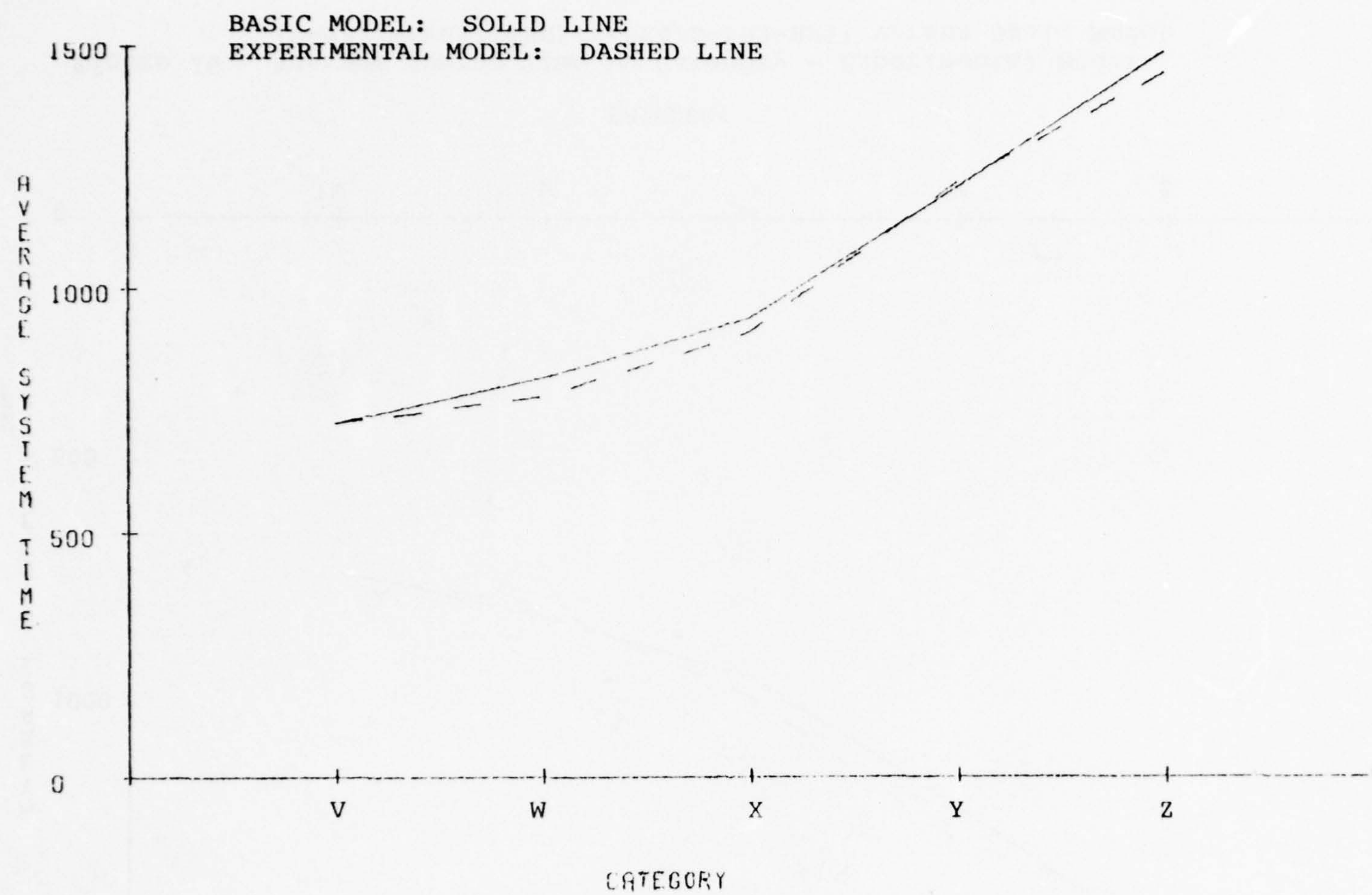

Figure 25. Average System Time by Category - Experimental Model (V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3-RN1) versus Basic Model

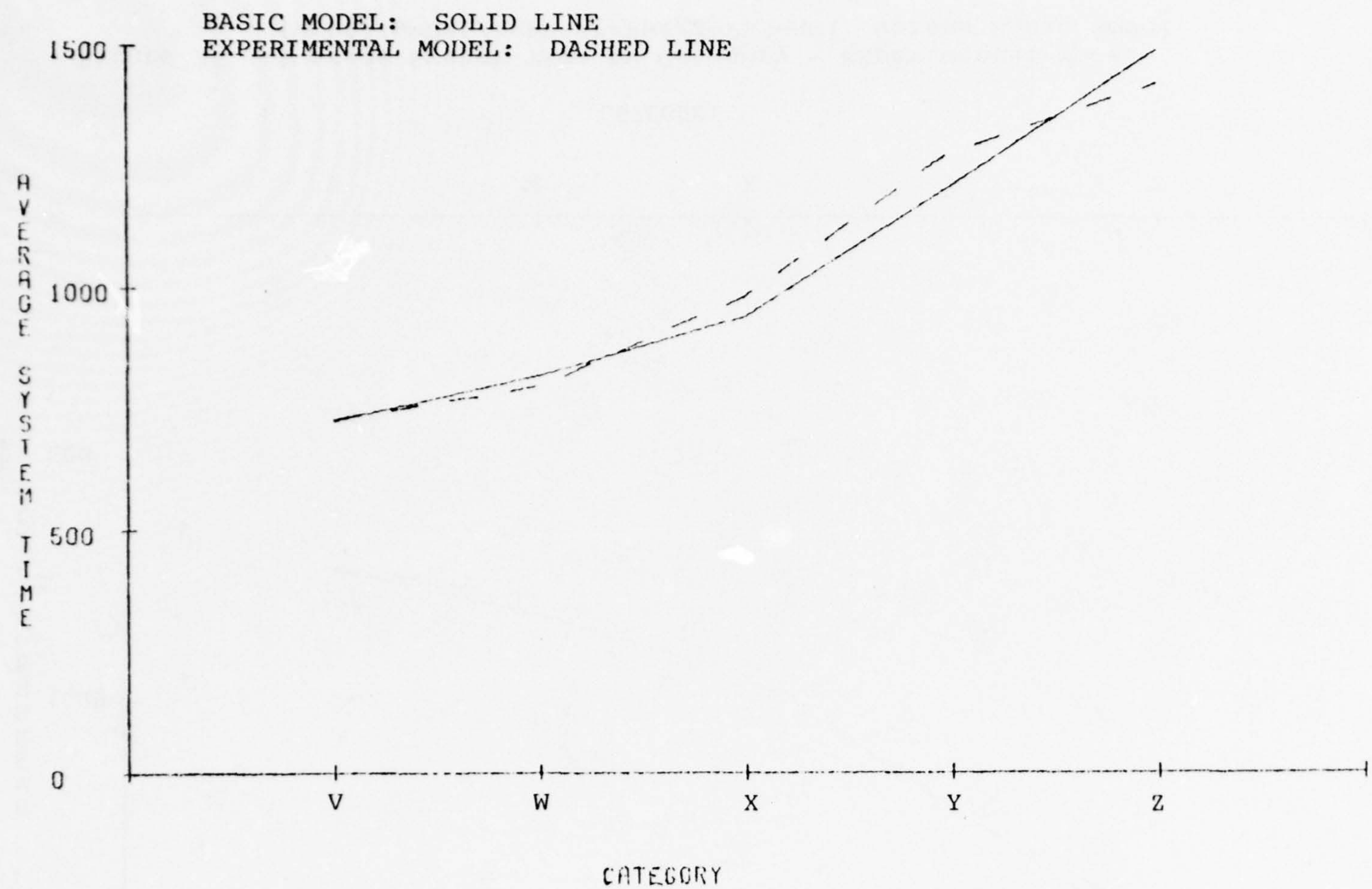

Figure 26. Average System Time by Category - Experimental Model (V=PR7/W=PR6/X=PR5/Y=PR4/Z=PR3-RN5) versus Basic Model

line is the basic model and the dashed line is the experimental model.

The efficiency factor for the experimental model using RN1 is -8.73. The experimental model using RN5 has an efficiency factor of +50.96. Inspection of the data failed to identify a pattern in the magnitude and direction of changes in $\overline{D}$, $\overline{\overline{D}}$, $\overline{ST}$, and $\overline{\overline{ST}}$ attributable to the experimental model.

The second experiment in this group tested a structuring of service priority by airspeed category based on a grouping of aircraft categories. Categories V, W and X were combined in one group and assigned PR5. Category Y and Z constituted a second group to which PR 3 was assigned. The basic model was altered to reflect this new priority schema and the experiment was conducted using first RN1 and then RN5.

The hypothesis underlying this experiment was that $\overline{\overline{ST}}$ would decrease at the expense of Categories Y and Z (i.e., $\overline{ST}$ for Categories Y and Z would increase while $\overline{ST}$ for Categories V, W and X decreased). Tables 23 and 24 present the computer output for this experiment. Table 23 is the computer output using RN1; Table 24 is the output using RN5.

Tables 23 and 24 were compared to Tables 13 and 14, respectively, to ascertain the nature of the changed in $\overline{D}$, $\overline{ST}$, $\overline{\overline{D}}$, and $\overline{\overline{ST}}$ produced by the experimental model. $\overline{ST}$ for Categories V, X, and Z decreased in the experimental model

Table 23.

Model Data: V,W,X=PR5/Y,Z=PR3(RN1)

TOTAL ARRIVALS: 507
TOTAL DEPARTURES: 420
MA(UP): 20
MA(P): 86

ROUTE	#	$\overline{D}$	$\overline{ST}$
DEP	420	59.8	-
VFR	33	50.0	155.6
OPW	163	28.7	895.4
RODA	17	62.1	1542.9
RODB	25	42.8	990.6
RID	13	39.1	2156.4
7OU	66	33.8	1090.3
3ZH	15	31.1	1383.9
EAT	41	32.1	1690.5
MA	106	609.4	778.0
HAA	11	351.5	2087.7
LAA	17	353.7	1866.5

CATEGORY	#	$\overline{ST}$
V	35	639.3
W	111	855.6
X	60	816.3
Y	77	1154.8
Z	191	1408.0

$\overline{\overline{D}} = 121.4$

$\overline{\overline{ST}} = 1044.0$

Table 24.

Model Data: V,W,X=PR5/Y,Z=PR3(RN5)

TOTAL ARRIVALS: 539
TOTAL DEPARTURES: 407
MA(UP): 24
MA(P): 94

ROUTE	#	$\overline{D}$	$\overline{ST}$
DEP	407	54.4	-
VFR	28	44.7	151.5
OPW	177	29.6	895.1
RODA	21	60.1	1511.9
RODB	21	40.7	964.1
RID	7	43.4	2156.3
7OU	65	30.5	1058.8
3ZH	12	25.8	1275.0
EAT	64	35.3	1696.3
MA	118	543.9	708.8
HAA	7	363.3	2124.7
LAA	19	312.3	1632.0

CATEGORY	#	$\overline{ST}$
V	58	615.7
W	145	811.8
X	60	873.0
Y	57	1226.8
Z	191	1424.1

$\overline{\overline{D}} = 114.4$

$\overline{\overline{ST}} = 1024.1$

(for both random number sequences) whereas $\overline{ST}$ for Categories W and Y fluctuated inconsistently. $\overline{\overline{ST}}$ decreased in the experimental model (both random number sequences) and $\overline{\overline{D}}$ remained the same or increased. A pattern of change was not identified. The efficiency factors for the experimental model using RN1 and RN5, were computed to be 103.59 and -104.79, respectively.

The third, and last, experiment involving service priority by aircraft speed category examined the effect of granting priority to only Category V aircraft. Category V was assigned PR5 and PR3 was assigned to the remaining categories. The hypothesis being tested was similar to those that preceded: $\overline{\overline{ST}}$ should decrease and the change should be reflected by a corresponding decrease in $\overline{ST}$ for Category V and an increase in $\overline{ST}$ for the remaining categories.

This experiment was also conducted using two different random number sequences (RN1, RN5) and the resultant computer outputs appear in Tables 25 and 26. The data tables were compared to those of the basic model. $\overline{ST}$ for Categories V and Z decreased in the experimental model while $\overline{ST}$ increased for Categories W and Y. $\overline{ST}$ for Category X did not experience a consistent change. $\overline{\overline{D}}$ was also inconsistent: it increased for RN1 and decreased for RN5. $\overline{\overline{ST}}$ decreased in the experimental model for both random number sequences. A pattern to characterize change in system parameters was not detected. An efficiency factor of 45.96 was computed

Table 25.

Model Data: V=PR5/W,X,Y,Z=PR3(RN1)

TOTAL ARRIVALS: 508
TOTAL DEPARTURES: 432
MA(UP): 19
MA(P): 72

ROUTE	#	$\bar{D}$	$\overline{ST}$
DEP	432	64.3	-
VFR	42	50.6	155.1
OPW	164	28.8	893.2
RODA	11	60.5	1501.5
RODB	24	40.0	1012.2
RID	8	38.0	2095.1
7OU	65	32.8	1054.4
3ZH	12	37.3	1444.3
EAT	57	36.8	1713.8
MA	91	527.5	698.6
HAA	10	340.5	1913.1
LAA	24	305.6	1583.8

CATEGORY	#	$\overline{ST}$
V	46	637.0
W	134	869.8
X	56	921.9
Y	53	1127.0
Z	177	1418.8

$\bar{\bar{D}} = 106.4$

$\overline{\overline{ST}} = 1013.5$

Table 26.

Model Data: V=PR5/W,X,Y,Z=PR3(RN5)

TOTAL ARRIVALS: 477
TOTAL DEPARTURES: 451
MA(UP): 18
MA(P): 66

ROUTE	#	$\bar{D}$	$\overline{ST}$
DEP	451	67.5	-
VFR	29	71.4	176.6
OPW	150	28.6	893.6
RODA	17	62.6	1564.0
RODB	19	42.1	973.4
RID	7	37.1	2001.0
7OU	76	35.8	1071.5
3ZH	13	28.7	1337.3
EAT	55	36.7	1723.6
MA	84	575.0	742.3
HAA	9	319.0	1474.2
LAA	18	308.9	1496.8

CATEGORY	#	$\overline{ST}$
V	41	669.9
W	133	862.9
X	55	987.7
Y	53	1199.8
Z	166	1380.5

$\bar{\bar{D}} = 108.6$

$\overline{\overline{ST}} = 1036.5$

for the experimental model using RN1. The efficiency factor for RN5 is -14.69.

Experiment Involving Arrival Route Re-design

One experiment of this type was conducted. It consisted of several alterations to the basic program to structure the arrival routes and the final approach course differently. A complete listing of the altered program is contained in Appendix B. In this revised system, all arriving aircraft are routed to an intermediate point twelve nautical miles Northeast of the FAF. From this point the aircraft fly a straight-in course to the FAF and continue to the runway. The revised system configuration is shown in Figure 27.

The airspace between the FAF and the intermediate point allows the controller to provide altitude separation for aircraft proceeding to the FAF. The fastest category of aircraft being considered in the model can descend 4000 feet between the intermediate point and the FAF using a descent rate of 1000 feet per minute. Therefore, four levels of altitude are provided in the model for aircraft arriving at the intermediate point. Aircraft at the highest level (6000 feet mean sea level) must begin descent immediately after departing the intermediate point. Aircraft at the second level (5000) can maintain that level for up to three nautical miles before beginning descent. Aircraft at each lower level

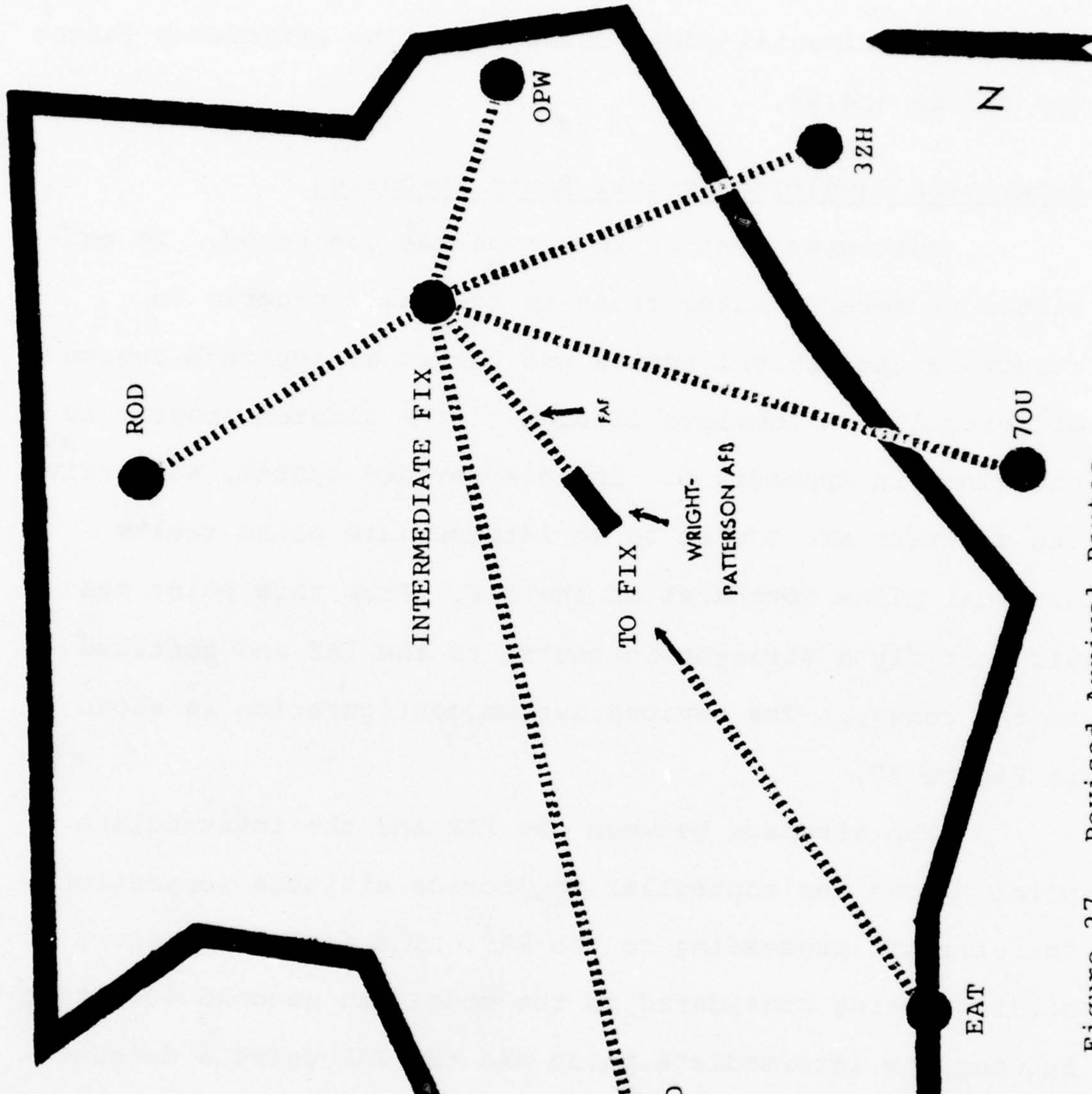

Figure 27. Revised Arrival Routes

can maintain their altitude progressively longer. Aircraft at the fifth, and lowest level, do not descent until reaching the FAF. It should be recognized that when an aircraft departs a particular altitude, the altitude below must be clear of other aircraft. "Facilities" were used in the model to replicate this situation. An aircraft descending to the next lower level will "sieze" the "facility" (representing the airspace it is entering) thus precluding entry of other aircraft. The arrangement of facilities used in the model is conceptualized in Figure 28. The remainder of the model was retained in its original form.

The altered model was run on the computer using RN1 and RN5. Tables 27 and 28 present a summary of the computer output. Comparison of $\overline{\overline{ST}}$ with the basic model reveals a decrease using both RN1 and RN5. $\overline{\overline{D}}$ decreased using RN5 and increased slightly using RN1. A graphic comparison of $\overline{ST}$ by route, $\overline{D}$ by route, and $\overline{ST}$ by category is presented in Figures 29 through 34. In each figure, the solid line is the basic model and the dashed line is the experimental model. As with previous experiments, no consistency in direction or magnitude of change was identified, nor was a pattern of change detected. The value of the efficiency factor for this model is +27.14 when RN1 is used, and -103.56 when RN5 is used.

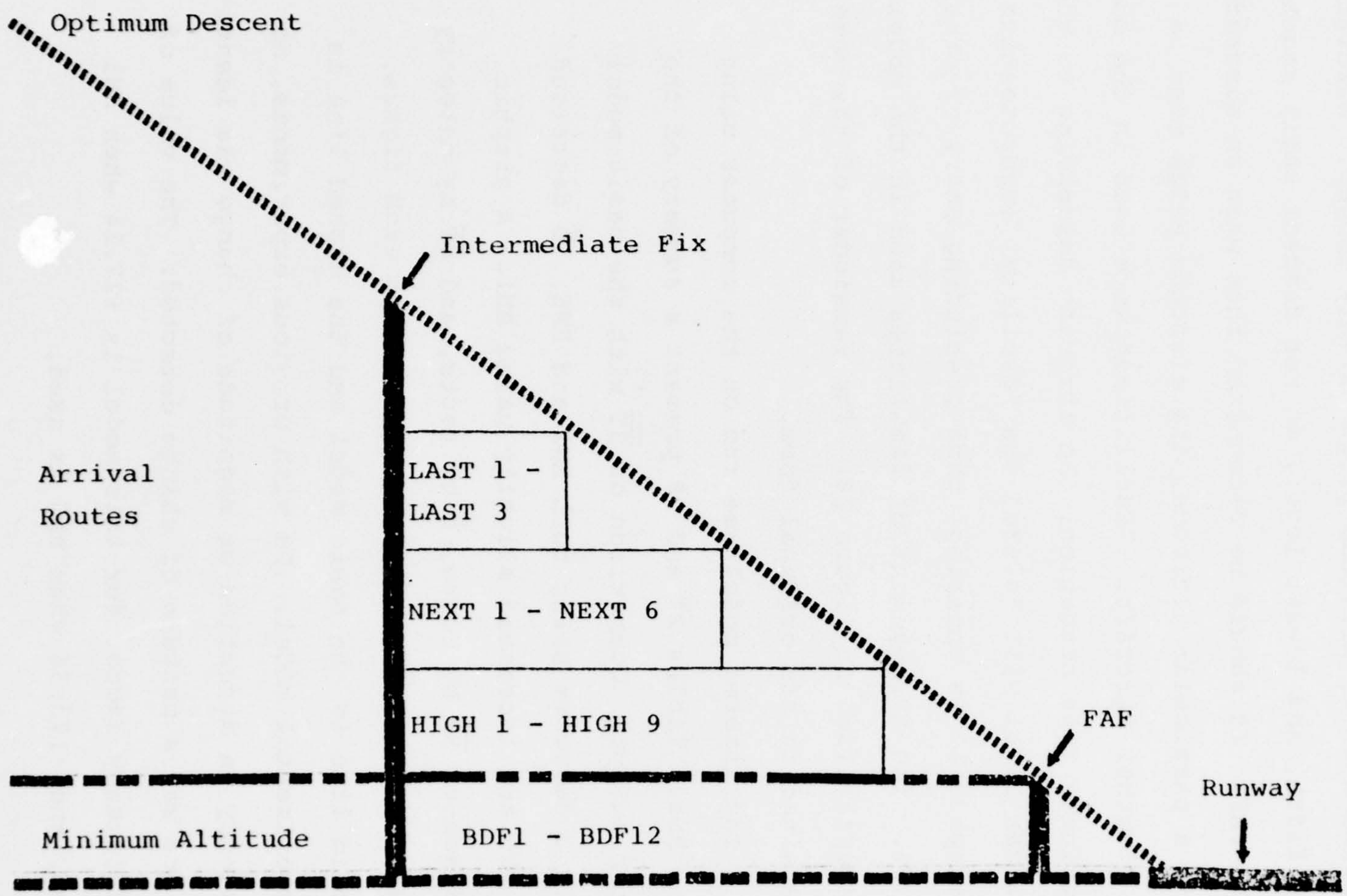

Figure 28. Arrangement of Facilities in "Straight In" Model

Table 27.

Model Data: Straight In (RN1)

TOTAL ARRIVALS: 502
TOTAL DEPARTURES: 433
MA(UP): 6
MA(P): 78

ROUTE	#	$\overline{D}$	$\overline{ST}$
DEP	433	44.7	-
VFR	46	91.4	197.5
OPW	157	28.7	925.3
RODA	-	-	-
RODB	36	36.3	1048.5
RID	10	31.5	1628.3
7OU	63	35.7	1210.9
3ZH	14	22.9	1420.7
EAT	65	36.8	1905.5
MA	84	587.7	763.4
HAA	11	307.6	1977.6
LAA	17	309.5	1581.1

CATEGORY	#	$\overline{ST}$
V	24	710.7
W	115	888.3
X	70	937.8
Y	72	1200.3
X	175	1486.0

$\overline{\overline{D}} = 99.1$

$\overline{\overline{ST}} = 1076.5$

Table 28.

Model Data: Straight In (RN5)

TOTAL ARRIVALS: 508
TOTAL DEPARTURES: 412
MA(UP): 18
MA(P): 76

ROUTE	#	$\overline{D}$	$\overline{ST}$
DEP	412	56.0	-
VFR	33	58.6	163.6
OPW	176	30.2	948.1
RODA	-	-	-
RODB	42	40.4	1041.4
RID	8	46.6	2001.1
7OU	58	35.6	1201.1
3ZH	15	29.4	1505.7
EAT	52	32.6	1816.8
MA	94	538.4	716.6
HAA	6	357.0	1924.8
LAA	25	321.0	1606.1

CATEGORY	#	$\overline{ST}$
V	32	699.7
W	132	849.6
X	62	922.7
Y	64	1241.9
Z	185	1407.9

$\overline{\overline{D}} = 105.8$

$\overline{\overline{ST}} = 1057.3$

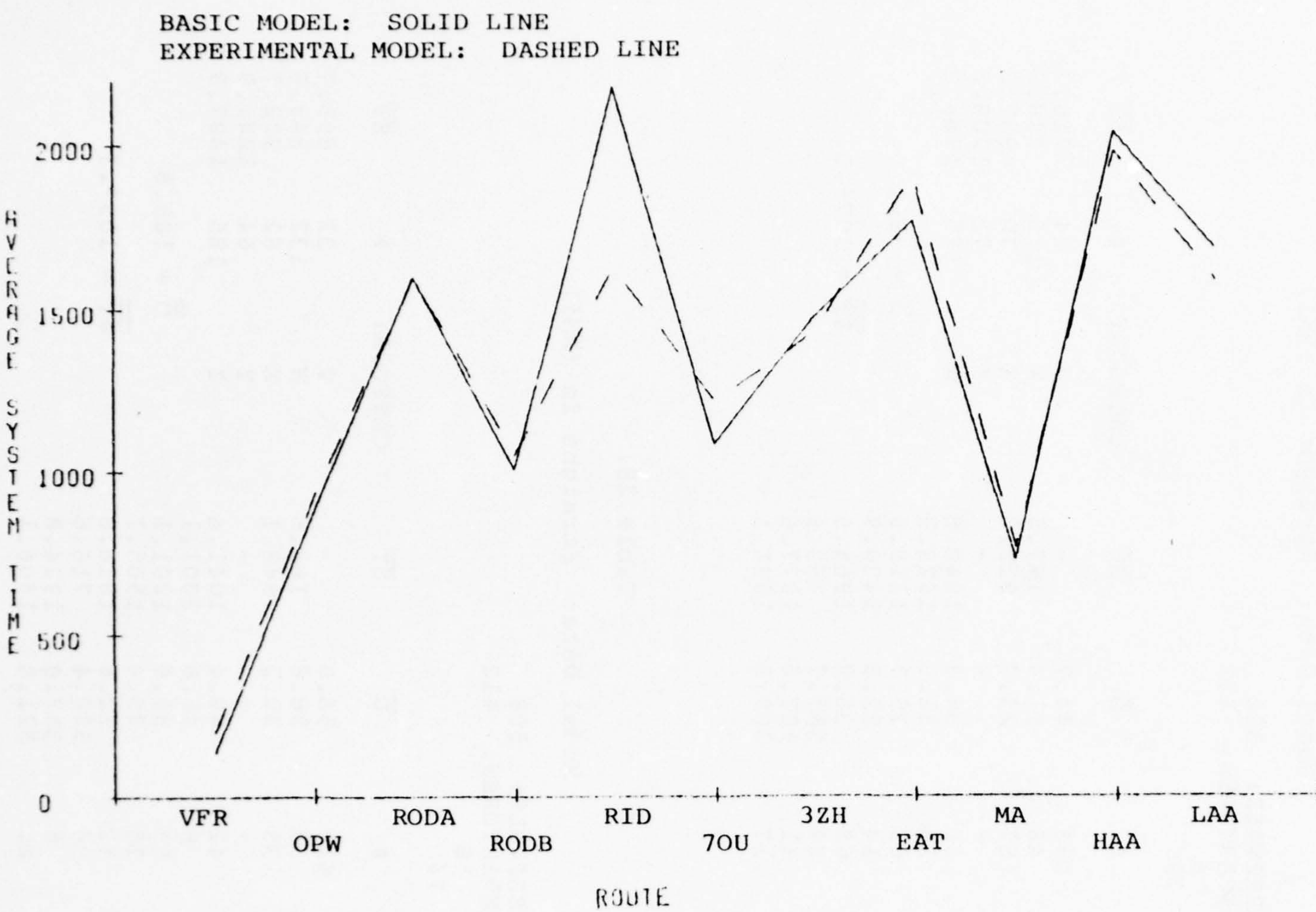

Figure 29. Average System Time by Route - Experimental Model (Straight In - RN1) versus Basic Model

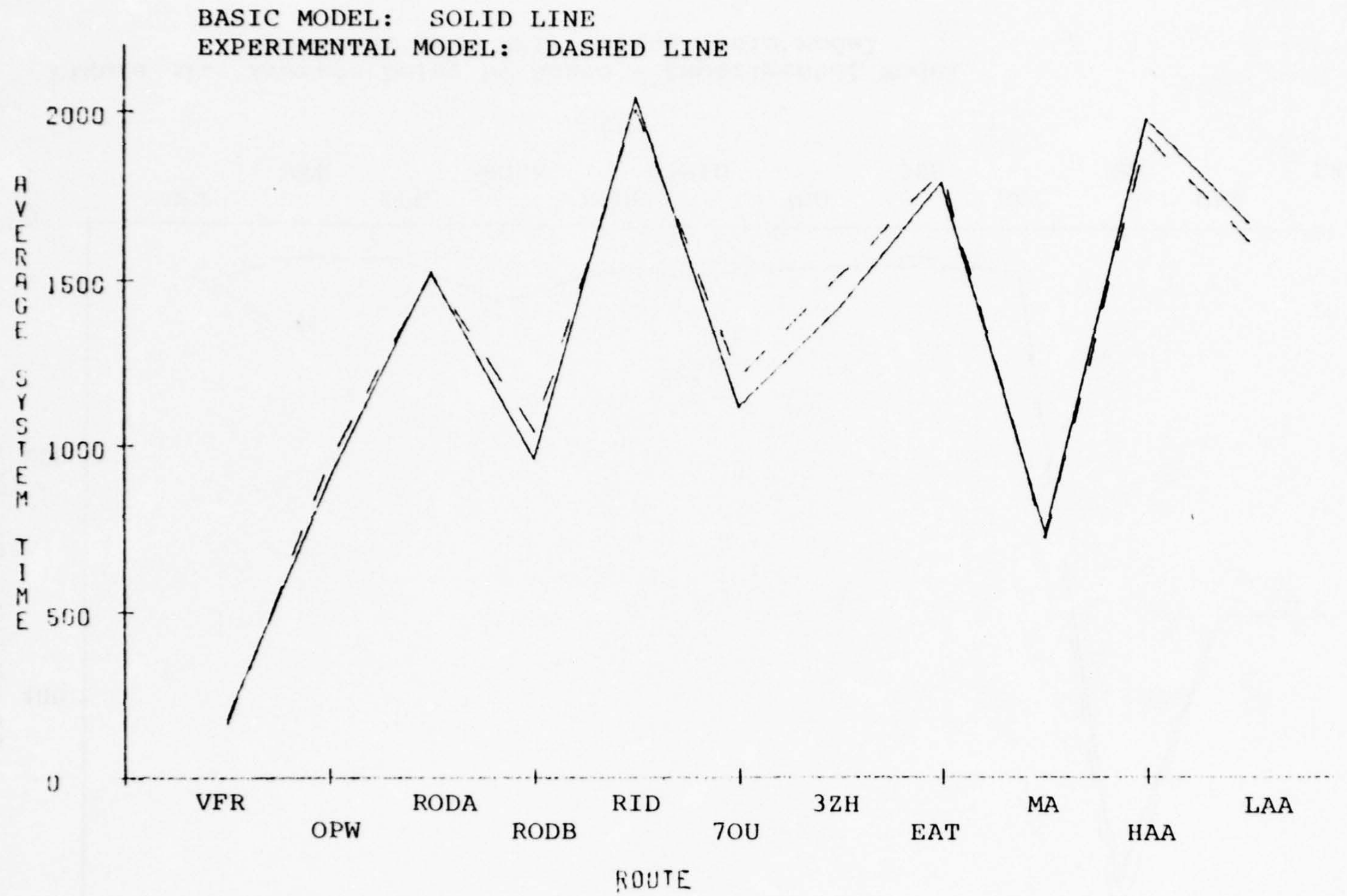

Figure 30. Average System Time by Route - Experimental Model (Straight In - RN5) versus Basic Model

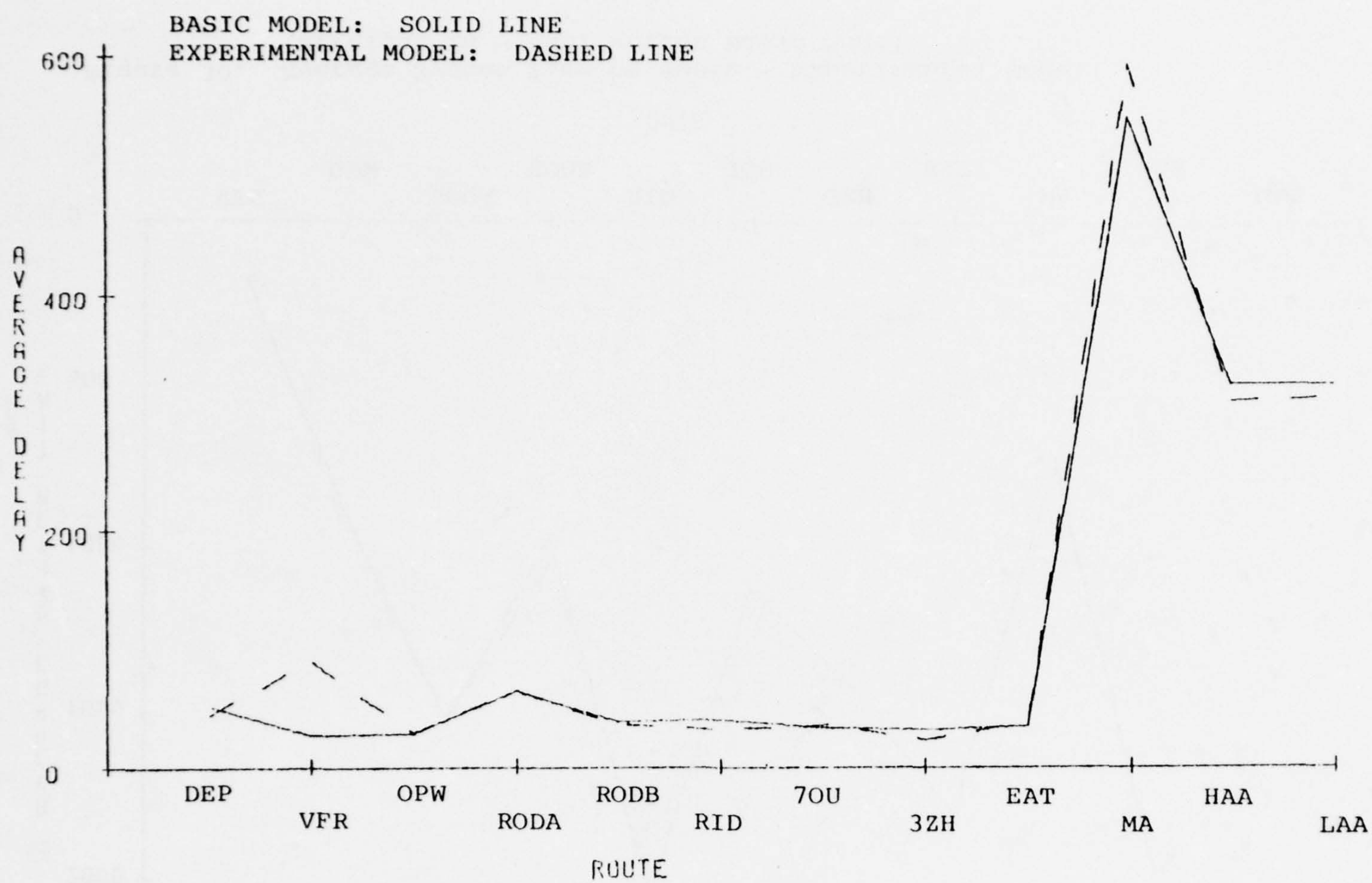

Figure 31. Average Delay by Route - Experimental Model (Straight In - RN1) versus Basic Model

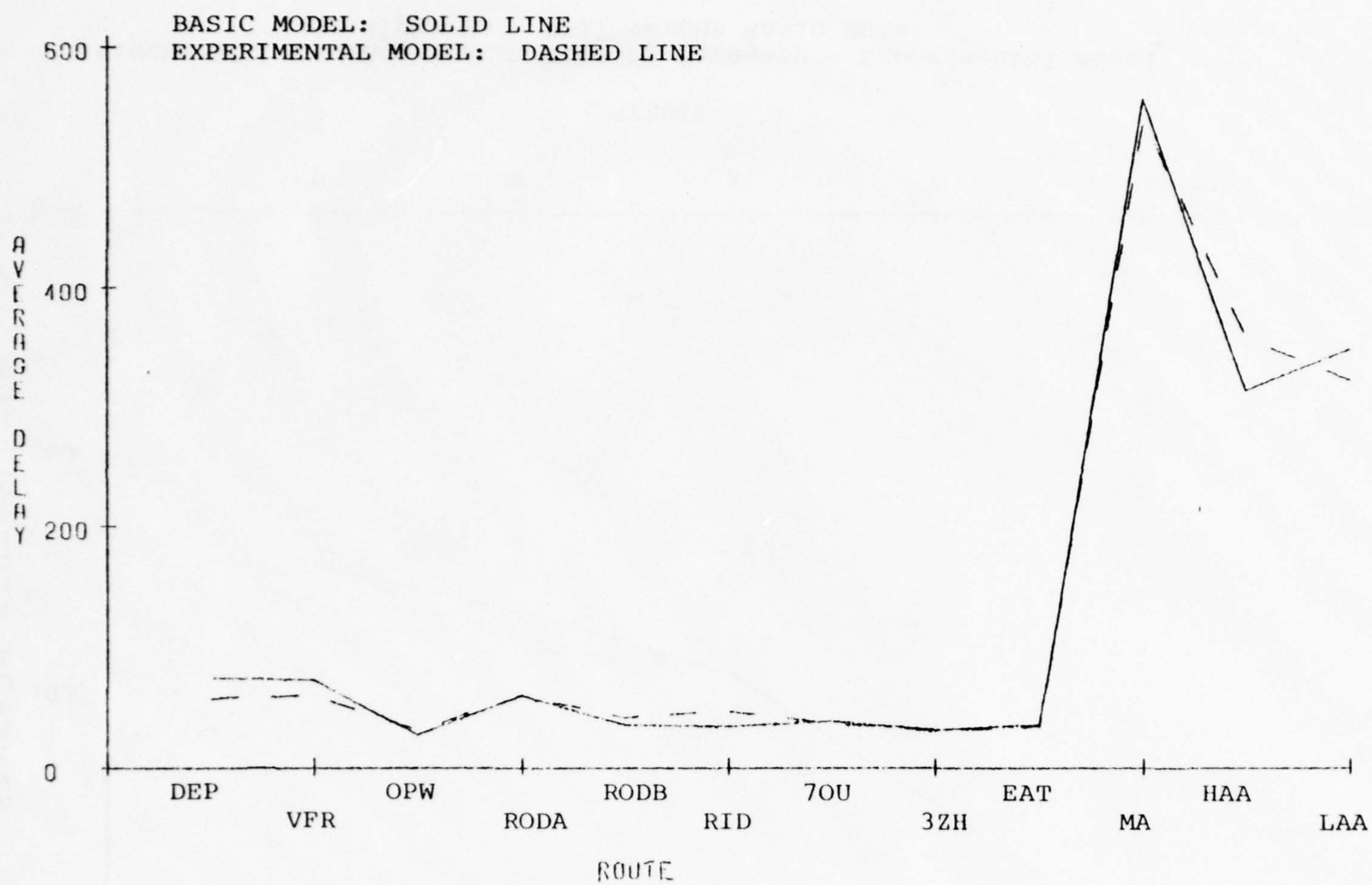

Figure 32. Average Delay by Route - Experimental Model (Straight In - RN5) versus Basic Model

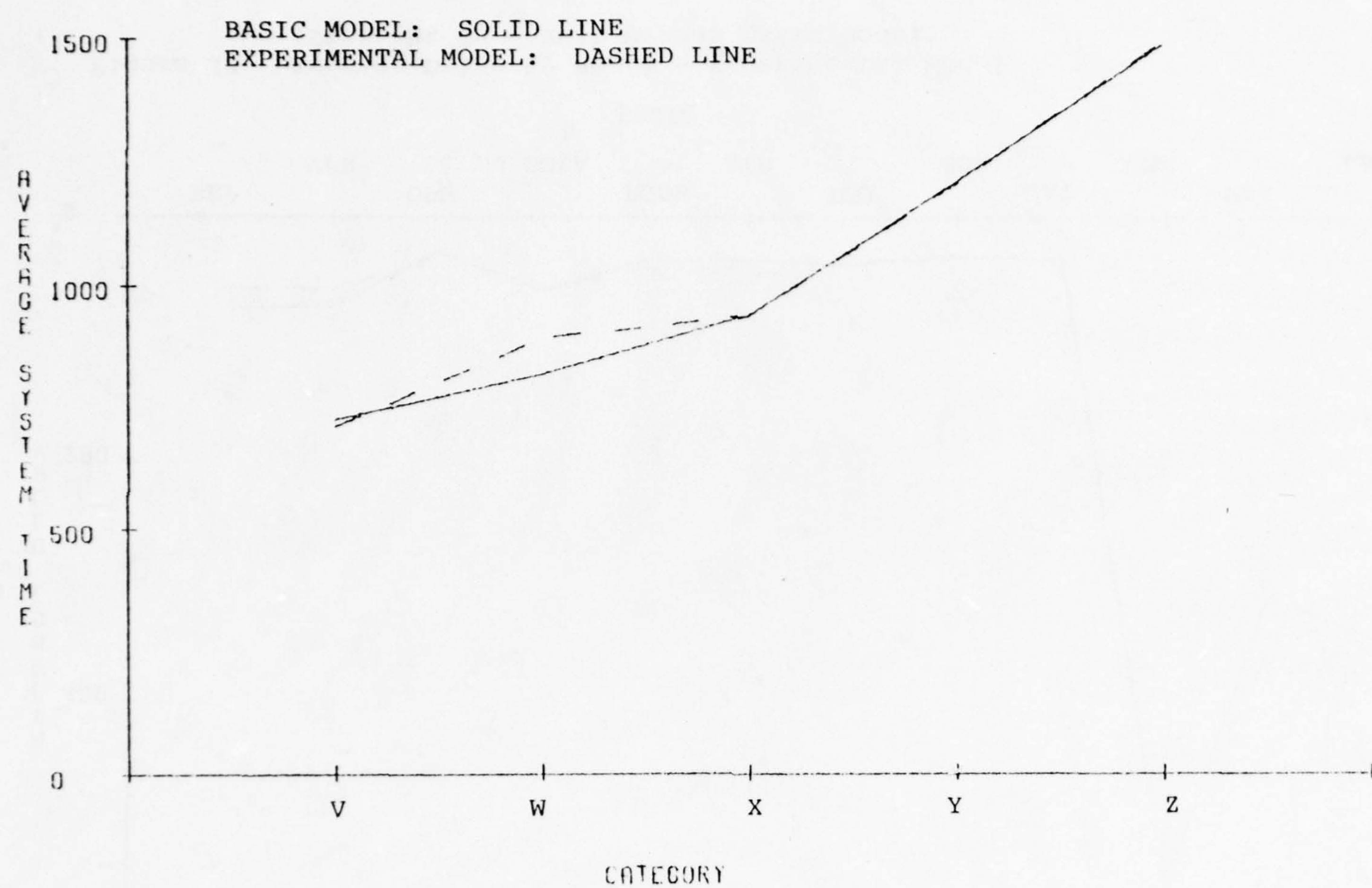

Figure 33. Average System Time by Category - Experimental Model (Straight In - RN1) versus Basic Model

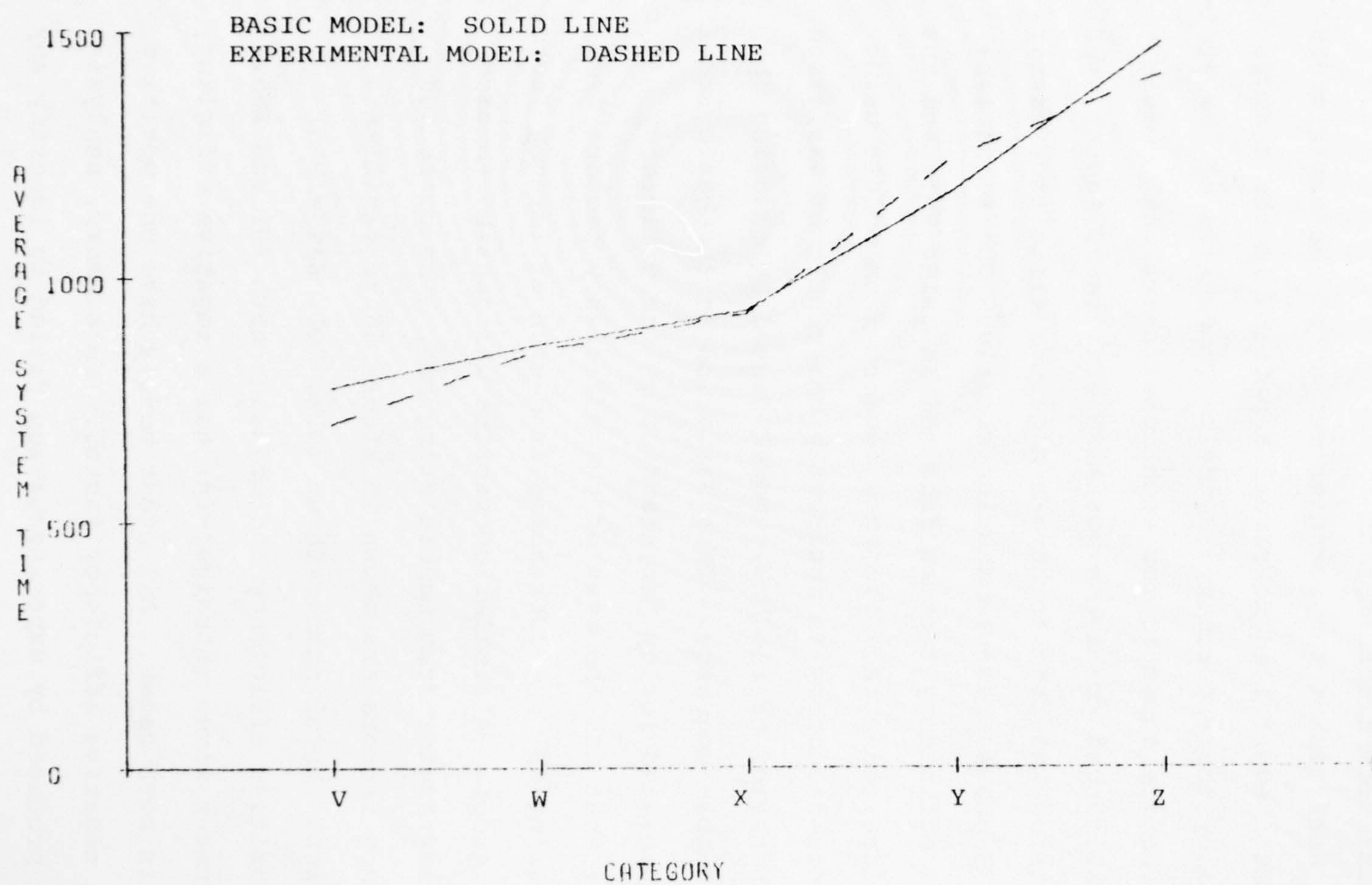

Figure 34. Average System Time by Category - Experimental Model (Straight In - RN5) versus Basic Model

Summary of Experiment Results

Analysis of the computer output of the experiments described above failed to reveal a pattern in the changes produced by the experimental model. Comparison of the efficiency factors computed for each model shows that models using RN1 tended to have a positive efficiency factor, while models using RN5 tend to have a negative efficiency factor. Figure 35 shows these tendencies clearly. The solid line connects efficiency factors from models using RN1, and the dashed line connects efficiency factors from models using RN5. This dichotomy is apparently the result of variation in the behavior of the basic model caused by changing the random number sequence. This variation in the basic model was compensated for by "standardizing" the efficiency factors; that is, the mean of the efficiency factors from models using RN1 was subtracted from each efficiency factor in that group. A similar correction was applied to each efficiency factor from models using RN5. The corrected efficiency factors are shown in Figure 36 to facilitate comparison. Model number three (OPW, 7OU, EAT = PR5) has a positive efficiency factor using both RN1 and RN5. Model number seven (Straight-In) has a negative efficiency factor in both cases. All other models have one positive and one negative efficiency factor. In summary, analysis of data produced by experimentation failed to identify any significant changes in system performance.

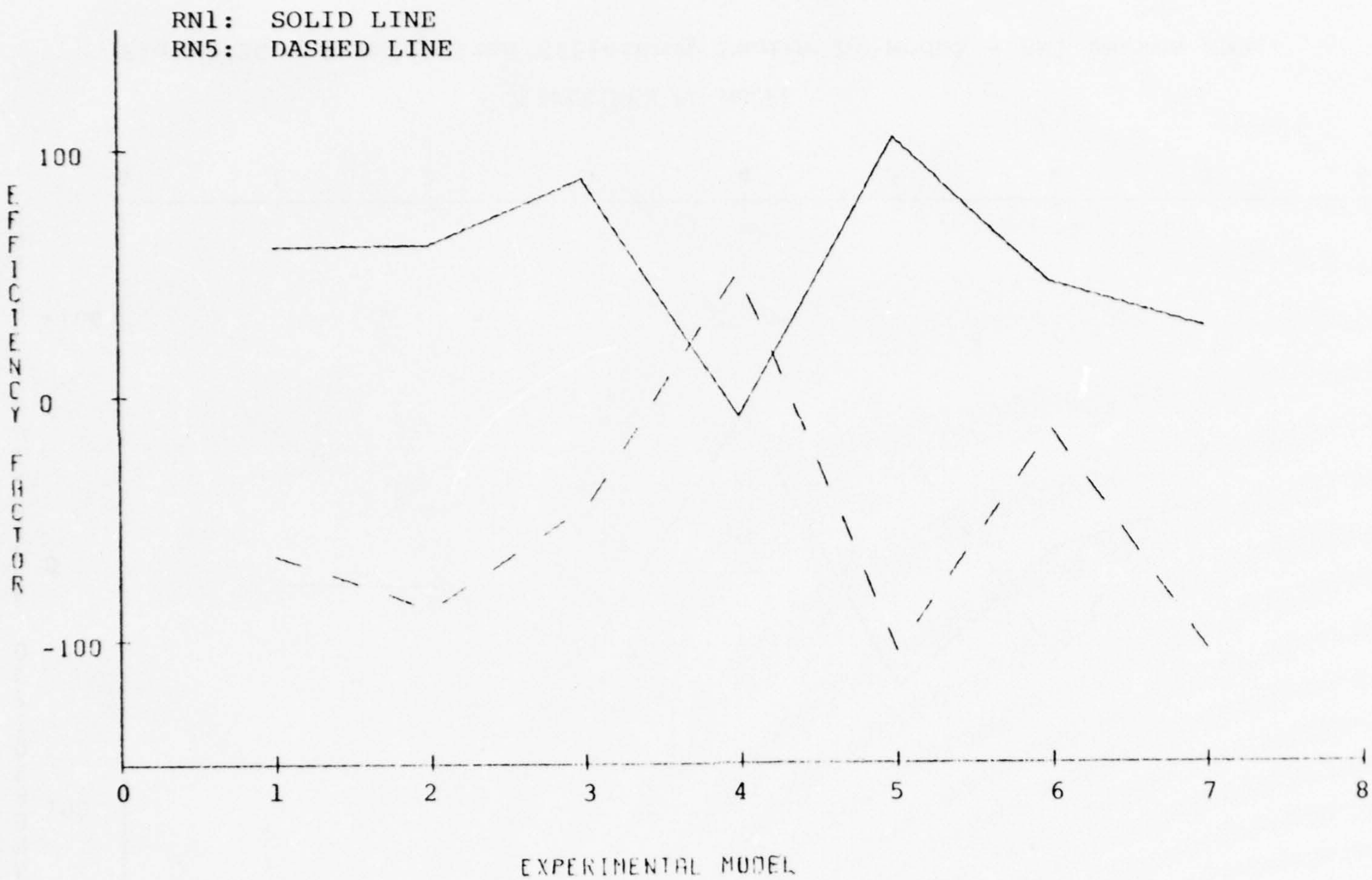

Figure 35. Efficiency Factor by Model - RN1 versus RN5

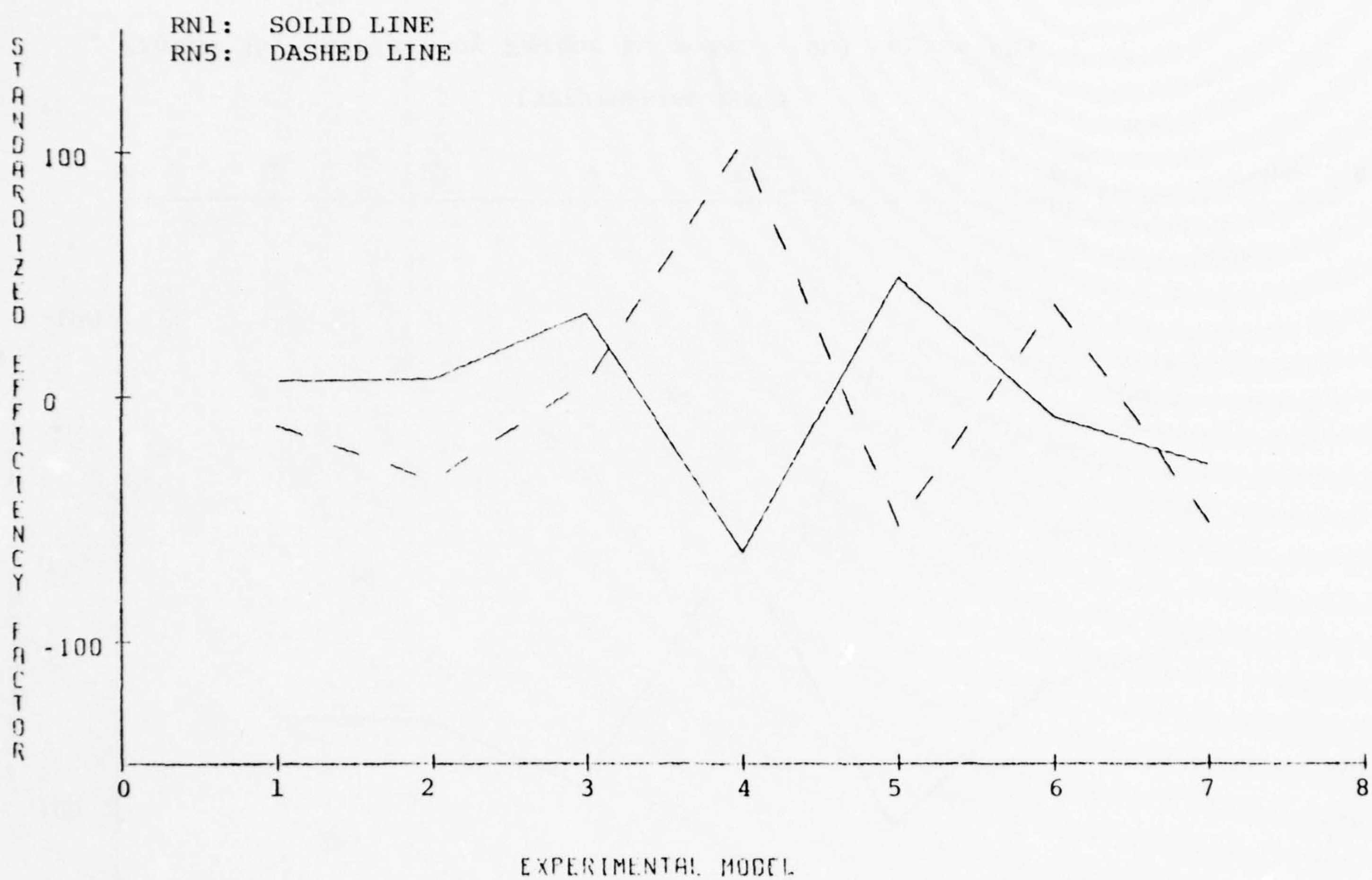

Figure 36. Standardized Efficiency Factor by Model - RN1 versus RN5

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Four research questions were posed in Chapter 1. Chapter 5 addresses these questions under two major subareas: (1) Conclusions, and (2) Recommendations for Future Research.

Conclusions

The first research question was : Can the variables comprising the military ATC environment be adequately represented by a computer model? The development process of the Dayton ACA simulation model and its subsequent validation indicate that the military ATC environment lends itself well to computer simulation. It has been concluded that the Dayton ACA model is a satisfactory representation of the true environment. This conclusion was considered a prerequisite for subsequent use of the model in experimentation.

The second research question was: Can changes in the terminal environment be effectively evaluated by the simulation model? Several experiments were conducted with the model to test various hypotheses related to the efficiency of the total system. The data resulting from the experiments fluctuated with apparent randomness. Possible causes for the fluctuations include: (1) low traffic volume at Wright-Patterson; (2) inadequate correction for variation in speed

category mix within the simulation model; (3) insufficient length in the simulation run, and (4) treatment of missed approaches in the simulation. Each of these possible causes is discussed below.

The volume of air traffic using Wright-Patterson is well below system capacity. This low traffic volume could account for the random fluctuation in the data resulting from the experiments. The occurrence of greater or lesser amounts of aircraft delay could be attributable to chance conflict of aircraft rather than the experimental changes in the system.

The random fluctuation in output data suggests the length of the simulation runs may have been insufficient. This would mean that the simulation had not reached steady state conditions with respect to the characteristics of system aircraft. Results from the experimental models exhibited wide disparity in the number of aircraft, their categories, and their routes. The disparity can be accounted for, in part, by the effect of the PRIORITY block. As explained earlier, this statement causes GPSS to re-initiate scan of the current events chain resulting in re-distribution of aircraft. The effect of the re-distribution could be dampened by lengthening the computer simulation run. Alternatively, the effect of the PRIORITY block might be eliminated by more sophisticated programming techniques.

A consequence of the re-distribution could be the generation of a higher or lower percentage of aircraft, in the experimental model, of a particular category than in the basic model. Similarly, there could be a higher or lower percentage on a particular SVR. The impact of these changes on a given experiment is not known with certainty. The correction factor (a_i) applied in the computation of the efficiency factor may not have adequately compensated for the changes. The weight of the correction factor can be changed by changing the value of k (100).

Another possible cause of the fluctuation in the data resulting from experimentation is the treatment of missed approaches (MAs) in the model. In the majority of experiments, the changes in $\overline{D}$ for MA aircraft tended to dominate the statistics for the total system, possibly obscuring some change pattern otherwise identifiable. In the analysis of the computer output of the various models (described earlier) the entire time required by an aircraft to execute an MA was treated as delay time.

No conclusions could be drawn from the experiments conducted with the simulation model because of the randomness exhibited by the data. The possible causes for the random fluctuation in the data discussed above indicate that the model is not necessarily ineffective in evaluation of experiments. Therefore, the research question remains unanswered.

The last two research questions dealt with prediction of conflict and conflict resolution. These areas were not addressed by this research due to the time constraints imposed by the academic situation.

Recommendations for Future Research

Further research is recommended in the following areas. First, addition experiments should be conducted with the model. This research was limited to experiments involving priority changes and one attempt at system redesign. There is a wide variety of design configurations and traffic control decision rules that could be tested other than those chosen.

If further experiments are conducted, the following recommendations apply. The length of the simulation run should be increased to insure that steady state conditions are reached. In addition, the simulation model should be artificially forced to contend with a greater volume of traffic than is characteristic of the real system. This could be accomplished by reducing the mean time between aircraft arrivals. The increased volume of traffic would preclude the domination of the statistical output by the chance occurrence of conflict.

Another recommendation is that MAs be treated differently. One possible approach is to treat planned MAs as a separate traffic classification and record as delay

only that time in excess of the normal time to execute a missed approach procedure. Unplanned MAs could be handled separately and treated as additional delay. The number of unplanned MAs could also be used as an independent criterion of system efficiency.

The next two recommendations deal with potential use of simulation in an on-line, real-time context. Toward this end, the simulation model could be used to evaluate the feasibility of identifying conflict in a real traffic environment. It is recommended that the GPSS program be modified to permit evaluation of traffic conflict in the model through comparative analysis of aircraft estimated arrival times at points in the system. This could be accomplished with an algorithm similar to MACRO eight which allows the controller to resequence aircraft by using airspeed control. This recommendation is directed toward answering research question three.

The final recommendation addresses research question four which concerns the use of the simulation model as a means of evaluating alternative solutions to conflict (2:245-252). The feasibility of using on-line, real-time simulation in an ATC environment could be evaluated by the model. Once conflict is identified in the manner described above, the algorithm could be expanded to compare various estimated arrival times based on hypothetical changes in

airspeed or vectoring route of the aircraft involved in the conflict. If the algorithm finds a combination of changes that resolves the conflict, those changes would be made to the appropriate aircraft. The results obtained from an experimental model using this algorithm could be compared with results from the basic model to determine its effectiveness.

Ideally, a simulation model would be on-line in an ATC facility computer, and available to continuously evaluate existing traffic using an heuristic search procedure. The best solution to a predicted conflict situation, as indicated by evaluation of alternatives through simulation, would be provided to the controller. Therefore, it is recommended that future research explore the possibility of using simulation in this context.

APPENDIX A

APPENDIX A

This appendix contains the simulation program used to model the Dayton Approach Control Area. The program is written in GPSS language and was executed on a 635 Honeywell Computer located at Headquarters, AFLC, Wright-Patterson AFB, Ohio. The program was stored in the CREATE time-sharing system using the file name SIM03, on user identification number 77A79 and password XS76.

```
0010##S,R(SL) :,8.16::,8,19,31
0020$:IDENT:WP1191,AFIT/SLG.  LORENZ AND GIBBAR  77A
0030$:PROGRAM:RLHS,ON1
0040$:LIMITS:5,39K,,5K
0050$:PRMFL:H*,R,R,AF.LIB/GPSSHS
0060$:FILE:*1,AIR,3L
0070$:FILE:*2,BIR,2L
0080$:FILE:*3,CIR,1L
0090;SIMULATE;,,2000
0100;CONTROL;BLO,650,VAR,80,QUE,60,FAC,30,FMS,15
0110;UNLIST
0120*
0130*DEFINITION OF MATRICES
0140*
0150 2;MATRIX;MH,5,11
0160 3;MATRIX;MH,5,11
0170 4;MATRIX;MH,5,11
0180 5;MATRIX;MH,5,11
0190 6;MATRIX;MH,5,11
0200 7;MATRIX;MH,5,11
0210 8;MATRIX;MH,5,11
0220 9;MATRIX;MH,5,11
0230 10;MATRIX;MF,12,8
0240 11;MATRIX;MF,5,1
0250 12;MATRIX;MF,5,1
0260 13;MATRIX;MF,5,1
0270;INITIAL;MF11-MF13(1-5,1),0
0280;INITIAL;MF10(1-12,1-8),0
0290;INITIAL;MH2-MH9(1-5,1-11),0
0300*
0310*FUNCTIONS
0320*
0330 1;FUNCTION;RN1,C24;EXPONENTIAL DISTRIBUTION
0340#0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915
0350#.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52
0360#.94,2.81/.95,2.99/.96,3.2/.97,3.5/.98,3.9/.99,4.6
0370#.995,5.3/.998,6.2/.999,7/.9998,8
0380 2;FUNCTION;RN1,C25;STANDARD NORMAL DISTRIBUTION
0390#0,-5/.00003,-4/.00135,-3/.00621,-2.5/.02275,-2
0400#.06681,-1.5/.11507,-1.2/.15866,-1/.21186,-.8/.27425,-.6
0410#.34458,-.4/.42074,-.2/.5,0/.57926,.2/.65542,.4
0420#.72575,.6/.78814,.8/.84134,1/.88493,1.2/.93319,1.5
0430#.97725,2/.99379,2.5/.99865,3/.99997,4/1,5
0440 3;FUNCTION;RN1,D2;RULES
0450#.7269,ADD1/.727,ADD2
0460 4;FUNCTION;RN1,D5;CATEGORY
0470#.062,ADD3/.310,ADD4/.434,ADD5/.562,ADD6/.5621,ADD7
0480 5;FUNCTION;RN1,D2;OPERATION 1
0490#.5,ADD8/.5001,ADD9
0500 6;FUNCTION;RN1,D3;OPERATION 2
0510#.536,ADD8/.965,ADD9/.9651,ADD10
0520 7;FUNCTION;RN1,D2;OPERATION 3
```

```
#.393,ADD8/.3931,ADD9
 8;FUNCTION;RN1,D3;OPERATION 4
#.483,ADD8/.897,ADD9/.8971,ADD10
 9;FUNCTION;RN1,D3;OPERATION 5
#.374,ADD8/.808,ADD9/.8081,ADD10
 10;FUNCTION;RN1,D3;AIRPORT
#.168,ADD11/.470,ADD12/.4701,ADD13
 11;FUNCTION;RN1,D5;ROUTE1
#.056,ADD14/.167,ADD15/.724,ADD16/.891,ADD17/.8911,ADD20
 12;FUNCTION;RN1,D6;ROUTE2
#.481,ADD15/.592,ADD16/.629,ADD17/.814,ADD18
#.851,ADD19/.8511,ADD20
 13;FUNCTION;RN1,D4;ROUTE3
#.222,ADD14/.500,ADD16/.870,ADD17/.8701,ADD20
 14;FUNCTION;FN2,C3;ADVANCE
#-5,.90/0,1.00/5,1.10
 15;FUNCTION;FN2,C3;IA
#-5,.80/0,1.00/5,1.20
*
*MACRO STATEMENTS
*
ONE;STARTMACRO
;MARK;1PF
;ASSIGN;23,#A,PL
;ASSIGN;24,#B,PL
;TRANSFER;.100,,ADD70
;ENDMACRO
*
TWO;STARTMACRO
;PREEMPT;#A,PR
;ADVANCE;PL14
;ENDMACRO
*
THREE;STARTMACRO
;PREEMPT;#A,PR
;ADVANCE;PL14
;RETURN;#B
;ENDMACRO
*
FOUR;STARTMACRO
;PREEMPT;#A,PR
;ADVANCE;PH15
;RETURN;#B
;ENDMACRO
*
FIVE;STARTMACRO
;ASSIGN;#A,#B,PL
;ASSIGN;#C,#D,PL
;ASSIGN;#E,#F,PL
;ENDMACRO
*
SIX;STARTMACRO
```

```
1050VAR#A;FVARIABLE;PL#B-PL25
1060;SAVEVALUE;#C,PL#B,XL
1070;ASSIGN;3,V$VAR#A,PH
1080;ADVANCE;V$VAR#A
1090;TRANSFER;,ADD30
1100;ENDMACRO
1110*
1120SEVEN;STARTMACRO
1130ADD#A;NULL
1140RTE#B;FVARIABLE;100/PL3*3600
1150SVR#B;FVARIABLE;#C/PL4*3600
1160;ADVANCE;V$RTE#B,FN14
1170ONE;MACRO;#D,#E
1180EIGHT;MACRO;#B,#G,#F
1190;ENDMACRO
1200*
1210EIGHT;STARTMACRO
1220ETA#A;VARIABLE;AC1+V$SVR#A
1230AETA#A;VARIABLE;V$ETA#A+V$VAR6
1240CETA#A;VARIABLE;V$ETA#A+V$VAR7-MF#B(PH6,1)
1250DETA#A;VARIABLE;V$AETA#A+V$VAR7-MF#B(PH6,1)
1260ADR1#A;TEST G;MF#B(PH6,1),Ø,ADR4#A
1270;TEST G;V$CETA#A,Ø,ADR2#A
1280;TEST G;V$DETA#A,Ø,ADR3#A
1290ADR2#A;SAVEVALUE;1Ø,V$ETA#A,XF
1300ADR4#A;LOOP;6PH,ADR1#A
1310;TRANSFER;,ADR8#A
1320ADR3#A;SAVEVALUE;1Ø,V$AETA#A,XF
1330ADR8#A;SAVEVALUE;11+,1,XH
1340;TEST GE;XH11,6,ADR7#A
1350;SAVEVALUE;11,1,XH
1360ADR7#A;TEST E;XF1Ø,V$AETA#A,ADR5#A
1370;MSAVEVALUE;#B,XH11,1,V$AETA#A,MF
1380ASVR#A;VARIABLE;V$SVR#A-V$VAR6
1390;ADVANCE;V$ASVR#A,FN14
1400;TRANSFER;,ADR6#A
1410ADR5#A;MSAVEVALUE;#B,XH11,1,V$ETA#A,MF
1420;ADVANCE;V$SVR#A,FN14
1430ADR6#A;TRANSFER;,#C
1440;ENDMACRO
1450*
1460*START
1470*
1480;GENERATE;82,FN1,,5ØØØ,3,4ØPL;2ØPH,15PF
1490;ASSIGN;6,5,PH
1500;ASSIGN;17,Ø,PH
1510;ASSIGN;18,12,PL
1520;ASSIGN;2,12,PL
1530;ASSIGN;6,12,PL
1540;ASSIGN;7,12,PL
1550*
1560*FLIGHT RULES
```

```
157Ø*
158Ø;TRANSFER;FN,3,Ø
159ØADD1;ASSIGN;1,1,PL
16ØØ;TRANSFER;FN,4,Ø
161ØADD2;ASSIGN;1,2,PL
162Ø;TRANSFER;,ADD1Ø2
163Ø*
164Ø*CATEGORY
165Ø*
166ØADD3;ASSIGN;2,9Ø,PH
167Ø;ASSIGN;2,1,PL
168ØFIVE;MACRO;3,55Ø,4,25Ø,5,17Ø
169Ø;TRANSFER;FN,5,Ø
17ØØADD4;ASSIGN;2,12Ø,PH
171Ø;ASSIGN;2,2,PL
172ØFIVE;MACRO;3,5ØØ,4,22Ø,5,16Ø
173Ø;TRANSFER;FN,6,Ø
174ØADD5;ASSIGN;2,6Ø,PH
175Ø;ASSIGN;2,3,PL
176ØFIVE;MACRO;3,3ØØ,4,17Ø,5,15Ø
177Ø;TRANSFER;FN,7,Ø
178ØADD6;ASSIGN;2,5Ø,PH
179Ø;ASSIGN;2,4,PL
18ØØFIVE;MACRO;3,25Ø,4,13Ø,5,11Ø
181Ø;TRANSFER;FN,8,Ø
182ØADD7;ASSIGN;2,2Ø,PH
183Ø;ASSIGN;2,5,PL
184ØFIVE;MACRO;3,14Ø,4,11Ø,5,8Ø
185Ø;TRANSFER;FN,9,Ø
186Ø*
187Ø*OPERATION
188Ø*
189ØADD8;ASSIGN;6,1,PL
19ØØ;TRANSFER;FN,1Ø,Ø
191ØADD9;ASSIGN;6,2,PL
192Ø;TRANSFER;FN,1Ø,Ø
193ØADD1Ø;ASSIGN;6,3,PL
194Ø;TRANSFER;,ADD1ØØ
195Ø*
196Ø*AIRPORT
197Ø*
198ØADD11;ASSIGN;7,1,PL
199Ø;TRANSFER;,ADD1ØØ
2ØØØADD12;ASSIGN;7,2,PL
2Ø1Ø;TEST E;PL6,1,ADD5Ø
2Ø2Ø;TRANSFER;FN,12,Ø
2Ø3ØADD13;ASSIGN;7,3,PL
2Ø4ØADD14;TRANSFER;,ADD1ØØ
2Ø5Ø*
2Ø6Ø*ROUTE
2Ø7Ø*
2Ø8ØADD15;ASSIGN;8,19,PL
```

```
2090FIVE;MACRO;9,2,10,2,18,1
2100;TRANSFER;,ADD21
2110ADD16;TRANSFER;.500,RODA,RODB
2120RODA;ASSIGN;8,42,PL
2130FIVE;MACRO;9,12,10,12,18,2
2140;TRANSFER;,ADD22
2150RODB;ASSIGN;8,25.5,PL
2160FIVE;MACRO;9,7.5,10,16.5,18,3
2170;TRANSFER;,ADD23
2180ADD17;ASSIGN;8,57,PL
2190FIVE;MACRO;9,4,10,7.5,18,4
2200;TRANSFER;,ADD24
2210ADD18;ASSIGN;8,24.5,PL
2220FIVE;MACRO;9,4,10,4,18,5
2230;TRANSFER;,ADD25
2240ADD19;ASSIGN;8,35,PL
2250FIVE;MACRO;9,2.5,10,6,18,6
2260;TRANSFER;,ADD26
2270ADD20;ASSIGN;8,52,PL
2280FIVE;MACRO;9,4,10,7.5,18,7
2290;TRANSFER;,ADD27
2300*
2310*0PW
2320*
2330VAR6;FVARIABLE;((10/PL4)-(10/PL5))*3600
2340VAR7;VARIABLE;PL14*3
2350SEVEN;MACRO;21,2,19,36,24,LEG,11
2360*
2370*ROD(A)
2380*
2390SEVEN;MACRO;22,3,42,29,37,FAF,12
2400*
2410*ROD(B)
2420*
2430SEVEN;MACRO;23,4,25.5,29,37,FAF,12
2440*
2450*RID
2460*
2470SEVEN;MACRO;24,5,57,28,44,BASE,13
2480*
2490*70U
2500*
2510SEVEN;MACRO;25,6,24.5,34,15,BASE,13
2520*
2530*3ZH
2540*
2550SEVEN;MACRO;26,7,35,28,17,BASE,13
2560*
2570*EAT
2580*
2590SEVEN;MACRO;27,8,52,27,35,BASE,13
2600*
```

```
261Ø*BASE LEG ENTRIES
262Ø*
263ØBASE;ENTER;1
264Ø;ASSIGN;16,13,PL
265Ø;ASSIGN;19,1,PL
266Ø;ASSIGN;15,AC1,PF
267ØBDL1;FVARIABLE;1/PL4*36ØØ*FN14
268ØFINAL;FVARIABLE;1/PL5*36ØØ*FN14
269Ø;ASSIGN;15,V$FINAL,PH
27ØØ;ASSIGN;14,V$BDL1,PL
271Ø;GATE NU;BDF1,ADD85
272ØTWO;MACRO;BDF1
273ØTWO;MACRO;BDF2
274ØTWO;MACRO;BDF3
275Ø;TEST E;PL4,22Ø,ADD9Ø
276Ø*
277Ø*HEAVIES FLY FINAL
278Ø*
279ØTHREE;MACRO;BDF4,BDF1
28ØØTHREE;MACRO;BDF5,BDF2
281ØADD28;PREEMPT;BDF6,PR
282Ø;ADVANCE;PL14
283Ø;RETURN;BDF3
284Ø;ENTER;1Ø
285ØFOUR;MACRO;BDF7,BDF4
286ØFOUR;MACRO;BDF8,BDF5
287ØFOUR;MACRO;BDF9,BDF6
288ØADD29;ENTER;11
289ØFOUR;MACRO;BDF1Ø,BDF7
29ØØFOUR;MACRO;BDF11,BDF8
291ØFOUR;MACRO;BDF12,BDF9
292Ø;PREEMPT;BDF13,PR
293Ø;ADVANCE;PH15
294ØADD33;TEST NE;PL18,8,ADD3Ø
295Ø;TEST NE;PL18,9,ADD62
296Ø;TEST NE;PL18,1Ø,ADD8Ø
297Ø;TEST NE;PL18,11,ADD8Ø
298Ø;SPLIT;5,ADD95,17PH
299Ø*
3ØØØ*COMPUTE DELAY TIMES
3Ø1Ø*
3Ø2Ø;SAVEVALUE;2-6,Ø,XL
3Ø3ØTIM1;FVARIABLE;AC1-PF15-(PL14*PL16)+((PH15-PL14)*7)
3Ø4Ø;ASSIGN;25,V$TIM1,PL
3Ø5ØDEL1;FVARIABLE;((PL9/PL4)*36ØØ)*FN14
3Ø6Ø;ASSIGN;26,V$DEL1,PL
3Ø7ØDEL2;FVARIABLE;((PL1Ø/PL4)*36ØØ)*FN14
3Ø8Ø;ASSIGN;27,V$DEL2,PL
3Ø9ØDEL3;FVARIABLE;((((1Ø/PL5)-(1Ø/PL4))*36ØØ)*FN14)+V$DEL2
31ØØ;ASSIGN;28,V$DEL3,PL
311ØDEL4;FVARIABLE;12Ø*FN14
312Ø;ASSIGN;29,V$DEL4,PL
```

```
313Ø;TEST GE;PL25,1,ADD3Ø
314Ø;TEST LE;PL25,PL26,ADD91
315ØSIX;MACRO;1,26,2
316Ø*
317ØADD91;TEST LE;PL25,PL27,ADD92
318ØSIX;MACRO;2,27,3
319Ø*
32ØØADD92;TEST LE;PL25,PL28,ADD93
321ØSIX;MACRO;3,28,4
322Ø*
323ØADD93;TEST LE;PL25,PL29,ADD94
324ØSIX;MACRO;4,29,5
325ØADD94;SAVEVALUE;6,PL25,XL
326Ø*
327Ø*RUNWAY
328Ø*
329ØADD3Ø;LEAVE;PL19
33ØØ;LEAVE;1Ø
331Ø;TRANSFER;.1ØØ,,ADD6Ø
332Ø;GATE NU;RWY,ADD6Ø
333Ø;PREEMPT;RWY,PR
334Ø;TEST E;PL4,22Ø,ADD31
335Ø;RETURN;BDF1Ø
336ØADD31;RETURN;BDF11
337Ø;RETURN;BDF12
338Ø;RETURN;BDF13
339Ø;ADVANCE;PH2,FN14
34ØØ;RETURN;RWY
341Ø;LEAVE;11
3415;TRANSFER;.Ø7Ø,,ADD64
342ØVAR5;VARIABLE;PF2-PF1
343Ø;MARK;2PF
344Ø;MSAVEVALUE;1Ø+,PL1,1,1,MF
345Ø;MSAVEVALUE;1Ø+,PL2,2,1,MF
346Ø;MSAVEVALUE;1Ø+,PL6,3,1,MF
347Ø;MSAVEVALUE;1Ø+,PL7,4,1,MF
348Ø;MSAVEVALUE;1Ø+,PL18,5,1,MF
349Ø;MSAVEVALUE;1Ø+,PL13,6,V$VAR5,MF
35ØØ;MSAVEVALUE;1Ø+,PL2,7,V$VAR5,MF
351Ø;MSAVEVALUE;1Ø+,PL2,8,1,MF
352Ø;SAVEVALUE;14+,V$VAR5,XF
354ØADD1ØØ;TERMINATE;1
355Ø*
356Ø*OTHERS FLY FINAL
357Ø*
358ØADD9Ø;RETURN;BDF1
359ØTHREE;MACRO;BDF4,BDF2
36ØØ;PREEMPT;BDF5,PR
361Ø;ADVANCE;PL14
362ØADD32;RETURN;BDF3
363ØTHREE;MACRO;BDF6,BDF4
364Ø;ENTER;1Ø
```

```
365ØFOUR;MACRO;BDF7,BDF5
366ØFOUR;MACRO;BDF8,BDF6
367Ø;PREEMPT;BDF9,PR
368Ø;ADVANCE;PH15
369ØADD34;RETURN;BDF7
370Ø;ENTER;11
371ØFOUR;MACRO;BDF1Ø,BDF8
372ØFOUR;MACRO;BDF11,BDF9
373ØADD36;PREEMPT;BDF12,PR
374Ø;ADVANCE;PH15
375Ø;RETURN;BDF1Ø
376Ø;PREEMPT;BDF13,PR
377Ø;ADVANCE;PH15
378Ø;TRANSFER;,ADD33
379Ø*
38ØØ*DOGLEG
381Ø*
382ØLEG;ENTER;2
383Ø;ASSIGN;16,11,PL
384Ø;ASSIGN;19,2,PL
385Ø;ASSIGN;15,AC1,PF
386ØBDL2;FVARIABLE;1/PL4*36ØØ*FN14
387Ø;ASSIGN;15,V$FINAL,PH
388Ø;ASSIGN;14,V$BDL2,PL
389Ø;GATE NU;BDF3,ADD86
39ØØTWO;MACRO;BDF3
391ØTWO;MACRO;BDF4
392ØTWO;MACRO;BDF5
393Ø;TEST E;PL4,22Ø,ADD32
394Ø;TRANSFER;,ADD28
395Ø*
396Ø*FINAL
397Ø*
398ØFAF;ENTER;3
399Ø;ASSIGN;16,7,PL
4ØØØ;ASSIGN;19,3,PL
4Ø1Ø;ASSIGN;15,AC1,PF
4Ø2ØBDL3;FVARIABLE;1/PL4*36ØØ*FN14
4Ø3Ø;ASSIGN;15,V$FINAL,PH
4Ø4Ø;ASSIGN;14,V$BDL3,PL
4Ø5Ø;PREEMPT;BDF7,PR
4Ø6ØIAP;ENTER;1Ø
4Ø7Ø;ADVANCE;PH15
4Ø8Ø;PREEMPT;BDF8,PR
4Ø9Ø;ADVANCE;PH15
41ØØ;PREEMPT;BDF9,PR
411Ø;ADVANCE;PH15
412Ø;TEST E;PL4,22Ø,ADD34
413Ø;TRANSFER;,ADD29
414Ø*
415Ø*QUEUES
416Ø*
```

```
417ØADD95;ASSIGN;15,PH17,PL
418ØADD96;ASSIGN;17,PH17,PL
419ØVAR1Ø;VARIABLE;PL17+PL18*5
42ØØ;QUEUE;V$VAR1Ø
421Ø;TEST NE;XL*PL15,Ø,ADD97
422Ø;MSAVEVALUE;PL15+,PL2,PL18,1,MH
423ØADD97;ASSIGN;22,V$VAR1Ø,PL
424Ø;ADVANCE;XL*PL15
425Ø;DEPART;PL22
426Ø;TERMINATE
427Ø*
428Ø*DEPARTURES
429Ø*
43ØØADD5Ø;QUEUE;2
431Ø;PRIORITY;2
432Ø;TEST G;Q2,5,ADD51
433Ø;PRIORITY;3
434ØADD51;TEST G;Q2,1Ø,ADD52
435Ø;PRIORITY;4
436ØADD52;GATE SE;11
437Ø;PREEMPT;RWY,PR
438Ø;DEPART;2
439Ø;ADVANCE;PH2,FN14
44ØØ;RETURN;RWY
441Ø;TRANSFER;,ADD1ØØ
442Ø*
443Ø*MISSED APPROACH
444Ø*
445ØADD6Ø;LEAVE;11
446ØADD63;TEST E;PL4,22Ø,ADD61
447Ø;RETURN;BDF1Ø
448ØADD61;RETURN;BDF11
449Ø;RETURN;BDF12
45ØØ;RETURN;BDF13
451ØADD64;MARK;2PF
4511;MSAVEVALUE;1Ø+,PL1,1,1,MF
4512;MSAVEVALUE;1Ø+,PL2,2,1,MF
4513;MSAVEVALUE;1Ø+,PL6,3,1,MF
4514;MSAVEVALUE;1Ø+,PL7,4,1,MF
4515;MSAVEVALUE;1Ø+,PL18,5,1,MF
4516;MSAVEVALUE;1Ø+,PL18,6,V$VAR5,MF
4517;MSAVEVALUE;1Ø+,PL2,7,V$VAR5,MF
4518;MSAVEVALUE;1Ø+,PL2,8,1,MF
4519;SAVEVALUE;14+,V$VAR5,XF
452Ø;MARK;1PF
4521;TEST NE;PL2,12,ADD1Ø3
4522;ENTER;6
453ØFIVE;MACRO;16,7,19,6,18,9
454Ø;ASSIGN;15,AC1,PF
456ØMAP;FVARIABLE;18/PL4*36ØØ
457Ø;ADVANCE;V$MAP,FN14
458Ø;PREEMPT;BDF7,PR
```

```
4590;TRANSFER;,IAP
4600ADD62;ASSIGN;17.0,PH
4610;ASSIGN;15,9,PL
4620;SPLIT;1,ADD96,17PH
4630;SAVEVALUE;9,V$TIM1,XL
4640;TRANSFER;,ADD30
4650*
4660*INSTRUMENT APPROACHES
4670*
4680ADD70;PRIORITY;2
4690;TEST NE;PL4,80,ADD71
4700;TRANSFER;.700,,ADD71
4710VAR11;FVARIABLE;PL23/PL3*3600
4720VAR12;FVARIABLE;((24/PL3)+(15/PL4))*3600
4730VAR13;FVARIABLE;6/PL4*3600
4740;ADVANCE;V$VAR11,FN15
4750;ENTER;4
4760FIVE;MACRO;16,7,19,4,18,10
4770;ASSIGN;15,AC1,PF
4780BDL4;FVARIABLE;1/PL4*3600*FN14
4790;ASSIGN;14,V$BDL4,PL
4800;ASSIGN;15,V$FINAL,PH
4810;PREEMPT;HAA,PR
4820;ADVANCE;V$VAR12,FN15
4830;RETURN;HAA
4840;ADVANCE;V$VAR13,FN15
4850;PREEMPT;BDF7,PR
4860;TRANSFER;,IAP
4870*
4880ADD71;ASSIGN;18,11,PL
4890VAR14;FVARIABLE;PL24/PL4*3600
4900VAR15;FVARIABLE;17/PL4*3600
4910VAR16;FVARIABLE;2/PL5*3600
4920;ADVANCE;V$VAR14,FN15
4930;ENTER;5
4940;ASSIGN;16,7,PL
4950;ASSIGN;19,5,PL
4960;ASSIGN;15,AC1,PF
4970BDL5;FVARIABLE;1/PL4*3600*FN14
4980;ASSIGN;14,V$BDL5,PL
4990;ASSIGN;15,V$FINAL,PH
5000;PREEMPT;LAA,PR
5010;ADVANCE;V$VAR15,FN15
5020;RETURN;LAA
5030;ADVANCE;V$VAR16,FN15
5040;PREEMPT;BDF7,PR
5050;TRANSFER;,IAP
5060*
5070ADD80;TEST NE;PL18,11,ADD81
5080;SAVEVALUE;7,0,XL
5090;ASSIGN;15,7,PL
5100;SPLIT;1,ADD96,17PH
```

```
5110TIM2;FVARIABLE;V$TIM1-V$VAR12-V$VAR13
5120;ASSIGN;30,V$TIM2,PL
5130;TEST GE;PL30,1,ADD30
5140;TEST LE;PL30,300,ADD82
5150;SAVEVALUE;7,300,XL
5160VAR17;FVARIABLE;300-PL30
5170;ADVANCE;V$VAR17
5180;TRANSFER;,ADD30
5190ADD82;SAVEVALUE;7,PL30,XL
5200;TRANSFER;,ADD30
5210*
5220ADD81;SAVEVALUE;8,0,XL
5230;ASSIGN;15,8,PL
5240;SPLIT;1,ADD96,17PH
5250TIM3;FVARIABLE;V$TIM1-V$VAR15-V$VAR16
5260;ASSIGN;31,V$TIM3,PL
5270;TEST GE;PL31,1,ADD30
5280;TEST LE;PL31,300,ADD83
5290;SAVEVALUE;8,300,XL
5300VAR18;FVARIABLE;300-PL31
5310;ADVANCE;V$VAR18
5320;TRANSFER;,ADD30
5330ADD83;SAVEVALUE;8,PL31,XL
5340;TRANSFER;,ADD30
5350*
5360*VFR
5370*
5380ADD102;TRANSFER;.943,,ADD100
5390ADD103;NULL
5400FIVE;MACRO;5,30,16,2,18,9
5410FIVE;MACRO;19,7,20,9,21,3
5420;ASSIGN;15,V$FINAL,PH
5430;ASSIGN;2,20,PH
5440;TRANSFER;.500,,ADD50
5450;MARK;1PF
5460;ENTER;7
5470;QUEUE;1
5480;GATE SE;10
5490;ENTER;10
5500;ENTER;11
5510;PREEMPT;BDF10,PR
5520;DEPART;1
5530;PREEMPT;BDF11,PR
5540;TRANSFER;,ADD36
5550*
5560*ALTITUDE
5570*
5580ADD85;ASSIGN;14,V$BDL1,PL
5590;ASSIGN;15,V$FINAL,PH
5600;ASSIGN;4,1,PH
5610TWO;MACRO;HIGH1
5620TWO;MACRO;HIGH2
```

```
5630ADD88;PREEMPT;HIGH3,PR
5640;ADVANCE;PL14
5650;TEST E;PL4,220,ADD87
5660;TEST E;PH4,1,ADD89
5670THREE;MACRO;HIGH4,HIGH1
5680THREE;MACRO;HIGH5,HIGH2
5690;TRANSFER;,ADD45
5700ADD89;NULL
5710THREE;MACRO;HIGH4,HIGH7
5720THREE;MACRO;HIGH5,HIGH8
5730ADD45;NULL
5740THREE;MACRO;HIGH6,HIGH3
5750;ENTER;10
5760FOUR;MACRO;BDF7,HIGH4
5770FOUR;MACRO;BDF8,HIGH5
5780FOUR;MACRO;BDF9,HIGH6
5790;TRANSFER;,ADD29
5800*
5810ADD86;ASSIGN;14,V$BDL2,PL
5820;ASSIGN;15,V$FINAL,PH
5830;PREEMPT;HIGH7,PR
5840;PREEMPT;HIGH8,PR
5850;TRANSFER;,ADD88
5860*
5870ADD87;TEST E;PH4,1,ADD46
5880;RETURN;HIGH1
5890THREE;MACRO;HIGH4,HIGH2
5900;TRANSFER;,ADD47
5910ADD46;RETURN;HIGH7
5920THREE;MACRO;HIGH4,HIGH8
5930ADD47;NULL
5940THREE;MACRO;HIGH5,HIGH3
5950THREE;MACRO;HIGH6,HIGH4
5960;ENTER;10
5970FOUR;MACRO;BDF7,HIGH5
5980FOUR;MACRO;BDF8,HIGH6
5990;PREEMPT;BDF9,PR
6000;ADVANCE;PL15
6010;TRANSFER;,ADD34
6020;LIST
6030;START;1000
6040;RESET
6045;INITIAL;MF10(1-12,1-8),0
6046;INITIAL;MH2-MH9(1-5,1-11),0
6050;START;4000,,,1
6060;END
6070$;ENDJOB
```

APPENDIX B

APPENDIX B

This appendix contains the simulation program used to model the "straight in" experimental design of the Dayton Approach Control Area. The program is written in GPSS language and was executed on a 635 Honeywell Computer located at Headquarters, AFLC, Wright-Patterson AFB, Ohio. The program was stored in the CREATE time-sharing system using the file name SIM02, on user identification number 77A79 and password XS76.

```
##S,R(SL) :,8,16;;,8,19,31
$:IDENT:WP1191,AFIT/SLG,  LORENZ AND GIBBAR  77A
$:PROGRAM:RLHS,ON1
$:LIMITS:5,39K,,5K
$:PRMFL:H*,R,R,AF.LIB/GPSSHS
$:FILE:*1,A1R,3L
$:FILE:*2,B1R,2L
$:FILE:*3,C1R,1L
;SIMULATE;,,2000
;CONTROL;BLO,700,VAR,80,QUE,60,FAC,50,FMS,15
;UNLIST
*
*DEFINITION OF MATRICES
*
 2;MATRIX;MH,5,11
 3;MATRIX;MH,5,11
 4;MATRIX;MH,5,11
 5;MATRIX;MH,5,11
 6;MATRIX;MH,5,11
 7;MATRIX;MH,5,11
 8;MATRIX;MH,5,11
 9;MATRIX;MH,5,11
 10;MATRIX;MF,12,8
 11;MATRIX;MF,15,1
 12;MATRIX;MF,15,1
 13;MATRIX;MF,15,1
;INITIAL;MF11-MF13(1-15,1),0
;INITIAL;MF10(1-12,1-8),0
;INITIAL;MH2-MH9(1-5,1-11),0
*
*FUNCTIONS
*
 1;FUNCTION;RN1,C24;EXPONENTIAL DISTRIBUTION
#0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915
#.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52
#.94,2.81/.95,2.99/.96,3.2/.97,3.5/.98,3.9/.99,4.6
#.995,5.3/.998,6.2/.999,7/.9998,8
 2;FUNCTION;RN1,C25;STANDARD NORMAL DISTRIBUTION
#0,-5/.00003,-4/.00135,-3/.00621,-2.5/.02275,-2
#.06681,-1.5/.11507,-1.2/.15866,-1/.21186,-.8/.27425,-.6
#.34458,-.4/.42074,-.2/.5,0/.57926,.2/.65542,.4
#.72575,.6/.78814,.8/.84134,1/.88493,1.2/.93319,1.5
#.97725,2/.99379,2.5/.99865,3/.99997,4/1,5
 3;FUNCTION;RN1,D2;RULES
#.7269,ADD1/.727,ADD2
 4;FUNCTION;RN1,D5;CATEGORY
#.062,ADD3/.310,ADD4/.434,ADD5/.562,ADD6/.5621,ADD7
 5;FUNCTION;RN1,D2;OPERATION 1
#.5,ADD8/.5001,ADD9
 6;FUNCTION;RN1,D3;OPERATION 2
#.536,ADD8/.965,ADD9/.9651,ADD10
 7;FUNCTION;RN1,D2;OPERATION 3
```

```
Ø530#.393,ADD8/.3931,ADD9
Ø540 8;FUNCTION;RN1,D3;OPERATION 4
Ø550#.483,ADD8/.897,ADD9/.8971,ADD1Ø
Ø560 9;FUNCTION;RN1,D3;OPERATION 5
Ø570#.374,ADD8/.8Ø8,ADD9/.8Ø81,ADD1Ø
Ø580 1Ø;FUNCTION;RN1,D3;AIRPORT
Ø590#.168,ADD11/.47Ø,ADD12/.47Ø1,ADD13
Ø6ØØ 11;FUNCTION;RN1,D5;ROUTE1
Ø61Ø#.Ø56,ADD14/.167,ADD15/.724,ADD16/.891,ADD17/.8911,ADD2Ø
Ø62Ø 12;FUNCTION;RN1,D6;ROUTE2
Ø63Ø#.481,ADD15/.592,ADD16/.629,ADD17/.814,ADD18
Ø64Ø#.851,ADD19/.8511,ADD2Ø
Ø65Ø 13;FUNCTION;RN1,D4;ROUTE3
Ø66Ø#.222,ADD14/.5ØØ,ADD16/.87Ø,ADD17/.87Ø1,ADD2Ø
Ø67Ø 14;FUNCTION;FN2,C3;ADVANCE
Ø68Ø#-5,.9Ø/Ø,1.ØØ/5,1.1Ø
Ø69Ø 15;FUNCTION;FN2,C3;IA
Ø7ØØ#-5,.8Ø/Ø,1.ØØ/5,1.2Ø
Ø71Ø*
Ø72Ø*MACRO STATEMENTS
Ø73Ø*
Ø74ØONE;STARTMACRO
Ø75Ø;MARK;1PF
Ø76Ø;ASSIGN;23,#A,PL
Ø77Ø;ASSIGN;24,#B,PL
Ø78Ø;TRANSFER;.1ØØ,,ADD7Ø
Ø79Ø;ENDMACRO
Ø8ØØ*
Ø81ØTWO;STARTMACRO
Ø82Ø;PREEMPT;#A,PR
Ø83Ø;ADVANCE;PL14
Ø84Ø;ENDMACRO
Ø85Ø*
Ø86ØTHREE;STARTMACRO
Ø87Ø;PREEMPT;#A,PR
Ø88Ø;ADVANCE;PL14
Ø89Ø;RETURN;#B
Ø9ØØ;ENDMACRO
Ø91Ø*
Ø92ØFOUR;STARTMACRO
Ø93Ø;PREEMPT;#A,PR
Ø94Ø;ADVANCE;PH15
Ø95Ø;RETURN;#B
Ø96Ø;ENDMACRO
Ø97Ø*
Ø98ØFIVE;STARTMACRO
Ø99Ø;ASSIGN;#A,#B,PL
1ØØØ;ASSIGN;#C,#D,PL
1Ø1Ø;ASSIGN;#E,#F,PL
1Ø2Ø;ENDMACRO
1Ø3Ø*
1Ø4ØSIX;STARTMACRO
```

```
1Ø5ØVAR#A;FVARIABLE;PL#B-PL25
1Ø6Ø;SAVEVALUE;#C,PL#B,XL
1Ø7Ø;ASSIGN;3,V$VAR#A,PH
1Ø8Ø;ADVANCE;V$VAR#A
1Ø9Ø;TRANSFER;,ADD3Ø
11ØØ;ENDMACRO
111Ø*
112ØSEVEN;STARTMACRO
113ØADD#A;NULL
114ØRTE#B;FVARIABLE;1ØØ/PL3*36ØØ
115ØSVR#B;FVARIABLE;#C/PL4*36ØØ
116Ø;ADVANCE;V$RTE#B,FN14
117ØONE;MACRO;#D,#E
118ØEIGHT;MACRO;#B,#G,#F
119Ø;ENDMACRO
12ØØ*
121ØEIGHT;STARTMACRO
122ØETA#A;VARIABLE;AC1+V$SVR#A
123ØAETA#A;VARIABLE;V$ETA#A+V$VAR6
124ØCETA#A;VARIABLE;V$ETA#A+V$VAR7-MF#B(PH6,1)
125ØDETA#A;VARIABLE;V$AETA#A+V$VAR7-MF#B(PH6,1)
126ØADR1#A;TEST G;MF#B(PH6,1),Ø,ADR4#A
127Ø;TEST G;V$CETA#A,Ø,ADR2#A
128Ø;TEST G;V$DETA#A,Ø,ADR3#A
129ØADR2#A;SAVEVALUE;1Ø,V$ETA#A,XF
13ØØADR4#A;LOOP;6PH,ADR1#A
131Ø;TRANSFER;,ADR8#A
132ØADR3#A;SAVEVALUE;1Ø,V$AETA#A,XF
133ØADR8#A;SAVEVALUE;11+,1,XH
134Ø;TEST GE;XH11,16,ADR7#A
135Ø;SAVEVALUE;11,1,XH
136ØADR7#A;TEST E;XF1Ø,V$AETA#A,ADR5#A
137Ø;MSAVEVALUE;#B,XH11,1,V$AETA#A,MF
138ØASVR#A;VARIABLE;V$SVR#A-V$VAR6
139Ø;ADVANCE;V$ASVR#A,FN14
14ØØ;TRANSFER;,ADR6#A
141ØADR5#A;MSAVEVALUE;#B,XH11,1,V$ETA#A,MF
142Ø;ADVANCE;V$SVR#A,FN14
143ØADR6#A;TRANSFER;,#C
144Ø;ENDMACRO
145Ø*
146Ø*START
147Ø*
148Ø;GENERATE;82,FN1,,5ØØØ,3,4ØPL,2ØPH,15PF
149Ø;ASSIGN;6,5,PH
15ØØ;ASSIGN;17,Ø,PH
151Ø;ASSIGN;18,12,PL
152Ø;ASSIGN;2,12,PL
153Ø;ASSIGN;6,12,PL
154Ø;ASSIGN;7,12,PL
155Ø*
156Ø*FLIGHT RULES
```

```
1570*
1580;TRANSFER;FN,3,0
1590ADD1;ASSIGN;1,1,PL
1600;TRANSFER;FN,4,0
1610ADD2;ASSIGN;1,2,PL
1620;TRANSFER;,ADD102
1630*
1640*CATEGORY
1650*
1660ADD3;ASSIGN;2,90,PH
1670;ASSIGN;2,1,PL
1680FIVE;MACRO;3,550,4,250,5,170
1690;TRANSFER;FN,5,0
1700ADD4;ASSIGN;2,120,PH
1710;ASSIGN;2,2,PL
1720FIVE;MACRO;3,500,4,220,5,160
1730;TRANSFER;FN,6,0
1740ADD5;ASSIGN;2,60,PH
1750;ASSIGN;2,3,PL
1760FIVE;MACRO;3,300,4,170,5,150
1770;TRANSFER;FN,7,0
1780ADD6;ASSIGN;2,50,PH
1790;ASSIGN;2,4,PL
1800FIVE;MACRO;3,250,4,130,5,110
1810;TRANSFER;FN,8,0
1820ADD7;ASSIGN;2,20,PH
1830;ASSIGN;2,5,PL
1840FIVE;MACRO;3,140,4,110,5,80
1850;TRANSFER;FN,9,0
1860*
1870*OPERATION
1880*
1890ADD8;ASSIGN;6,1,PL
1900;TRANSFER;FN,10,0
1910ADD9;ASSIGN;6,2,PL
1920;TRANSFER;FN,10,0
1930ADD10;ASSIGN;6,3,PL
1940;TRANSFER;,ADD100
1950*
1960*AIRPORT
1970*
1980ADD11;ASSIGN;7,1,PL
1990;TRANSFER;,ADD100
2000ADD12;ASSIGN;7,2,PL
2010;TEST E;PL6,1,ADD50
2020;TRANSFER;FN,12,0
2030ADD13;ASSIGN;7,3,PL
2040ADD14;TRANSFER;,ADD100
2050*
2060*ROUTE
2070*
2080ADD15;ASSIGN;8,19,PL
```

```
2Ø9ØFIVE;MACRO;9,2,1Ø,2,18,1
21ØØ;TRANSFER;,ADD21
211ØADD16;TRANSFER;,RODB
212ØRODA;ASSIGN;8,42,PL
213ØFIVE;MACRO;9,12,1Ø,12,18,2
214Ø;TRANSFER;,ADD22
215ØRODB;ASSIGN;8,25.5,PL
216ØFIVE;MACRO;9,7.5,1Ø,16.5,18,3
217Ø;TRANSFER;,ADD23
218ØADD17;ASSIGN;8,57,PL
219ØFIVE;MACRO;9,4,1Ø,7.5,18,4
22ØØ;TRANSFER;,ADD24
221ØADD18;ASSIGN;8,24.5,PL
222ØFIVE;MACRO;9,4,1Ø,4,18,5
223Ø;TRANSFER;,ADD25
224ØADD19;ASSIGN;8,35,PL
225ØFIVE;MACRO;9,2.5,1Ø,6,18,6
226Ø;TRANSFER;,ADD26
227ØADD2Ø;ASSIGN;8,52,PL
228ØFIVE;MACRO;9,4,1Ø,7.5,18,7
229Ø;TRANSFER;,ADD27
23ØØ*
231Ø*ØPW
232Ø*
233ØVAR6;FVARIABLE;((1Ø/PL4)-(1Ø/PL5))*36ØØ
234ØVAR7;VARIABLE;PL14*3
235ØSEVEN;MACRO;21,2,15,36,24,BASE,13
236Ø*
237Ø*ROD(A)
238Ø*
239ØSEVEN;MACRO;22,3,42,29,37,BASE,13
24ØØ*
241Ø*ROD(B)
242Ø*
243ØSEVEN;MACRO;23,4,2Ø.5,29,37,BASE,13
244Ø*
245Ø*RID
246Ø*
247ØSEVEN;MACRO;24,5,5Ø.5,28,44,BASE,13
248Ø*
249Ø*7OU
25ØØ*
251ØSEVEN;MACRO;25,6,24.5,34,15,BASE,13
252Ø*
253Ø*3ZH
254Ø*
255ØSEVEN;MACRO;26,7,37.5,28,17,BASE,13
256Ø*
257Ø*EAT
258Ø*
259ØSEVEN;MACRO;27,8,52,27,35,BASE,13
26ØØ*
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261Ø*STRAIGHT IN ENTRIES
262Ø*
263ØBASE;ENTER;1
264Ø;ASSIGN;16,16,PL
265Ø;ASSIGN;19,1,PL
266Ø;ASSIGN;15,AC1,PF
267ØBDL1;FVARIABLE;1/PL4*36ØØ*FN14
268ØFINAL;FVARIABLE;1/PL5*36ØØ*FN14
269Ø;ASSIGN;15,V$FINAL,PH
27ØØ;ASSIGN;14,V$BDL1,PL
271Ø;GATE NU;BDF1,ADD85
272ØTWO;MACRO;BDF1
273ØTWO;MACRO;BDF2
274ØTWO;MACRO;BDF3
275Ø;TEST E;PL4,22Ø,ADD9Ø
276Ø*
277Ø*HEAVIES FLY FINAL
278Ø*
279ØTHREE;MACRO;BDF4,BDF1
28ØØTHREE;MACRO;BDF4A,BDF2
281ØTHREE;MACRO;BDF4B,BDF3
282ØTHREE;MACRO;BDF4C,BDF4
283ØTHREE;MACRO;BDF5,BDF4A
284ØADD28;PREEMPT;BDF6,PR
285Ø;ADVANCE;PL14
286Ø;RETURN;BDF4B
287Ø;ENTER;1Ø
288ØFOUR;MACRO;BDF7,BDF4C
289ØFOUR;MACRO;BDF8,BDF5
29ØØFOUR;MACRO;BDF9,BDF6
291ØADD29;ENTER;11
292ØFOUR;MACRO;BDF1Ø,BDF7
293ØFOUR;MACRO;BDF11,BDF8
294ØFOUR;MACRO;BDF12,BDF9
295Ø;PREEMPT;BDF13,PR
296Ø;ADVANCE;PH15
297ØADD33;TEST NE;PL18,8,ADD3Ø
298Ø;TEST NE;PL18,9,ADD62
299Ø;TEST NE;PL18,1Ø,ADD8Ø
3ØØØ;TEST NE;PL18,11,ADD8Ø
3Ø1Ø;SPLIT;5,ADD95,17PH
3Ø2Ø*
3Ø3Ø*COMPUTE DELAY TIMES
3Ø4Ø*
3Ø5Ø;SAVEVALUE;2-6,Ø,XL
3Ø6ØTIM1;FVARIABLE;AC1-PF15-(PL14*PL16)+((PH15-PL14)*7)
3Ø7Ø;ASSIGN;25,V$TIM1,PL
3Ø8ØDEL1;FVARIABLE;((PL9/PL4)*36ØØ)*FN14
3Ø9Ø;ASSIGN;26,V$DEL1,PL
31ØØDEL2;FVARIABLE;((PL1Ø/PL4)*36ØØ)*FN14
311Ø;ASSIGN;27,V$DEL2,PL
312ØDEL3;FVARIABLE;((((1Ø/PL5)-(1Ø/PL4))*36ØØ)*FN14)+V$DEL2
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3130;ASSIGN;28,V$DEL3,PL
3140DEL4;FVARIABLE;120*FN14
3150;ASSIGN;29,V$DEL4,PL
3160;TEST GE;PL25,1,ADD30
3170;TEST LE;PL25,PL26,ADD91
3180SIX;MACRO;1,26,2
3190*
3200ADD91;TEST LE;PL25,PL27,ADD92
3210SIX;MACRO;2,27,3
3220*
3230ADD92;TEST LE;PL25,PL28,ADD93
3240SIX;MACRO;3,28,4
3250*
3260ADD93;TEST LE;PL25,PL29,ADD94
3270SIX;MACRO;4,29,5
3280ADD94;SAVEVALUE;6,PL25,XL
3290*
3300*RUNWAY
3310*
3320ADD30;LEAVE;PL19
3330;LEAVE;10
3340;TRANSFER;.100,,ADD60
3350;GATE NU;RWY,ADD60
3360;PREEMPT;RWY,PR
3370;TEST E;PL4,220,ADD31
3380;RETURN;BDF10
3390ADD31;RETURN;BDF11
3400;RETURN;BDF12
3410;RETURN;BDF13
3420;ADVANCE;PH2,FN14
3430;RETURN;RWY
3440;LEAVE;11
3450;TRANSFER;.070,,ADD64
3460VAR5;VARIABLE;PF2-PF1
3470;MARK;2PF
3480;MSAVEVALUE;10+,PL1,1,1,MF
3490;MSAVEVALUE;10+,PL2,2,1,MF
3500;MSAVEVALUE;10+,PL6,3,1,MF
3510;MSAVEVALUE;10+,PL7,4,1,MF
3520;MSAVEVALUE;10+,PL18,5,1,MF
3530;MSAVEVALUE;10+,PL18,6,V$VAR5,MF
3540;MSAVEVALUE;10+,PL2,7,V$VAR5,MF
3550;MSAVEVALUE;10+,PL2,8,1,MF
3560;SAVEVALUE;14+,V$VAR5,XF
3570ADD100;TERMINATE;1
3580*
3590*OTHERS FLY FINAL
3600*
3610ADD90;RETURN;BDF1
3620THREE;MACRO;BDF4,BDF2
3630THREE;MACRO;BDF4A,BDF3
3640THREE;MACRO;BDF4B,BDF4
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THREE;MACRO;BDF4C,BDF4A
;PREEMPT;BDF5,PR
;ADVANCE;PL14
ADD32;RETURN;BDF4B
THREE;MACRO;BDF6,BDF4C
;ENTER;10
FOUR;MACRO;BDF7,BDF5
FOUR;MACRO;BDF8,BDF6
;PREEMPT;BDF9,PR
;ADVANCE;PH15
ADD34;RETURN;BDF7
;ENTER;11
FOUR;MACRO;BDF10,BDF8
FOUR;MACRO;BDF11,BDF9
ADD36;PREEMPT;BDF12,PR
;ADVANCE;PH15
;RETURN;BDF10
;PREEMPT;BDF13,PR
;ADVANCE;PH15
;TRANSFER;,ADD33
*
*INTERCEPT FINAL
*
IAP;ENTER;10
;ADVANCE;PH15
;PREEMPT;BDF8,PR
;ADVANCE;PH15
;PREEMPT;BDF9,PR
;ADVANCE;PH15
;TEST E;PL4,220,ADD34
;TRANSFER;,ADD29
*
*QUEUES
*
ADD95;ASSIGN;15,PH17,PL
ADD96;ASSIGN;17,PH17,PL
VAR10;VARIABLE;PL17+PL18*5
;QUEUE;V$VAR10
;TEST NE;XL*PL15,0,ADD97
;MSAVEVALUE;PL15+,PL2,PL18,1,MH
ADD97;ASSIGN;22,V$VAR10,PL
;ADVANCE;XL*PL15
;DEPART;PL22
;TERMINATE
*
*DEPARTURES
*
ADD50;QUEUE;2
;PRIORITY;2
;TEST G;Q2,5,ADD51
;PRIORITY;3
ADD51;TEST G;Q2,10,ADD52
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417Ø;PRIORITY;4
418ØADD52;GATE SE;11
419Ø;PREEMPT;RWY,PR
42ØØ;DEPART;2
421Ø;ADVANCE;PH2,FN14
422Ø;RETURN;RWY
423Ø;TRANSFER;,ADD1ØØ
424Ø*
425Ø*MISSED APPROACH
426Ø*
427ØADD6Ø;LEAVE;11
428ØADD63;TEST E;PL4,22Ø,ADD61
429Ø;RETURN;BDF1Ø
43ØØADD61;RETURN;BDF11
431Ø;RETURN;BDF12
432Ø;RETURN;BDF13
433ØADD64;MARK;2PF
434Ø;MSAVEVALUE;1Ø+,PL1,1,1,MF
435Ø;MSAVEVALUE;1Ø+,PL2,2,1,MF
436Ø;MSAVEVALUE;1Ø+,PL6,3,1,MF
437Ø;MSAVEVALUE;1Ø+,PL7,4,1,MF
438Ø;MSAVEVALUE;1Ø+,PL18,5,1,MF
439Ø;MSAVEVALUE;1Ø+,PL18,6,V$VAR5,MF
44ØØ;MSAVEVALUE;1Ø+,PL2,8,1,MF
441Ø;MSAVEVALUE;1Ø+,PL2,7,V$VAR5,MF
442Ø;SAVEVALUE;14+,V$VAR5,XF
443Ø;MARK;1PF
444Ø;TEST NE;PL2,12,ADD1Ø3
445Ø;ENTER;6
446ØFIVE;MACRO;16,7,19,6,18,9
447Ø;ASSIGN;15,AC1,PF
448ØMAP;FVARIABLE;18/PL4*36ØØ
449Ø;ADVANCE;V$MAP,FN14
45ØØ;PREEMPT;BDF7,PR
451Ø;TRANSFER;,IAP
452ØADD62;ASSIGN;17,Ø,PH
453Ø;ASSIGN;15,9,PL
454Ø;SPLIT;1,ADD96,17PH
455Ø;SAVEVALUE;9,V$TIM1,XL
456Ø;TRANSFER;,ADD3Ø
457Ø*
458Ø*INSTRUMENT APPROACHES
459Ø*
46ØØADD7Ø;PRIORITY;2
461Ø;TEST NE;PL4,8Ø,ADD71
462Ø;TRANSFER;.7ØØ,,ADD71
463ØVAR11;FVARIABLE;PL23/PL3*36ØØ
464ØVAR12;FVARIABLE;((24/PL3)+(15/PL4))*36ØØ
465ØVAR13;FVARIABLE;6/PL4*36ØØ
466Ø;ADVANCE;V$VAR11,FN15
467Ø;ENTER;4
468ØFIVE;MACRO;16,7,19,4,18,1Ø
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469Ø;ASSIGN;15,AC1,PF
47ØØBDL4;FVARIABLE;1/PL4*36ØØ*FN14
471Ø;ASSIGN;14,V$BDL4,PL
472Ø;ASSIGN;15,V$FINAL,PH
473Ø;PREEMPT;HAA,PR
474Ø;ADVANCE;V$VAR12,FN15
475Ø;RETURN;HAA
476Ø;ADVANCE;V$VAR13,FN15
477Ø;PREEMPT;BDF7,PR
478Ø;TRANSFER;,IAP
479Ø*
48ØØADD71;ASSIGN;18,11,PL
481ØVAR14;FVARIABLE;PL24/PL4*36ØØ
482ØVAR15;FVARIABLE;17/PL4*36ØØ
483ØVAR16;FVARIABLE;2/PL5*36ØØ
484Ø;ADVANCE;V$VAR14,FN15
485Ø;ENTER;5
486Ø;ASSIGN;16,7,PL
487Ø;ASSIGN;19,5,PL
488Ø;ASSIGN;15,AC1,PF
489ØBDL5;FVARIABLE;1/PL4*36ØØ*FN14
49ØØ;ASSIGN;14,V$BDL5,PL
491Ø;ASSIGN;15,V$FINAL,PH
492Ø;PREEMPT;LAA,PR
493Ø;ADVANCE;V$VAR15,FN15
494Ø;RETURN;LAA
495Ø;ADVANCE;V$VAR16,FN15
496Ø;PREEMPT;BDF7,PR
497Ø;TRANSFER;,IAP
498Ø*
499ØADD8Ø;TEST NE;PL18,11,ADD81
5ØØØ;SAVEVALUE;7,Ø,XL
5Ø1Ø;ASSIGN;15,7,PL
5Ø2Ø;SPLIT;1,ADD96,17PH
5Ø3ØTIM2;FVARIABLE;V$TIM1-V$VAR12-V$VAR13
5Ø4Ø;ASSIGN;3Ø,V$TIM2,PL
5Ø5Ø;TEST GE;PL3Ø,1,ADD3Ø
5Ø6Ø;TEST LE;PL3Ø,3ØØ,ADD82
5Ø7Ø;SAVEVALUE;7,3ØØ,XL
5Ø8ØVAR17;FVARIABLE;3ØØ-PL3Ø
5Ø9Ø;ADVANCE;V$VAR17
51ØØ;TRANSFER;,ADD3Ø
511ØADD82;SAVEVALUE;7,PL3Ø,XL
512Ø;TRANSFER;,ADD3Ø
513Ø*
514ØADD81;SAVEVALUE;8,Ø,XL
515Ø;ASSIGN;15,8,PL
516Ø;SPLIT;1,ADD96,17PH
517ØTIM3;FVARIABLE;V$TIM1-V$VAR15-V$VAR16
518Ø;ASSIGN;31,V$TIM3,PL
519Ø;TEST GE;PL31,1,ADD3Ø
52ØØ;TEST LE;PL31,3ØØ,ADD83
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521Ø;SAVEVALUE;8,3ØØ,XL
522ØVAR18;FVARIABLE;3ØØ-PL31
523Ø;ADVANCE;V$VAR18
524Ø;TRANSFER;,ADD3Ø
525ØADD83;SAVEVALUE;8,PL31,XL
526Ø;TRANSFER;,ADD3Ø
527Ø*
528Ø*VFR
529Ø*
53ØØADD1Ø2;TRANSFER;.943,,ADD1ØØ
531ØADD1Ø3;NULL
532ØFIVE;MACRO;5,8Ø,16,2,18,8
533ØFIVE;MACRO;19,7,2Ø,9,21,3
534Ø;ASSIGN;15,V$FINAL,PH
535Ø;ASSIGN;2,2Ø,PH
536Ø;TRANSFER;.5ØØ,,ADD5Ø
537Ø;MARK;1PF
538Ø;ENTER;7
539Ø;QUEUE;1
54ØØ;GATE SE;1Ø
541Ø;ENTER;1Ø
542Ø;ENTER;11
543Ø;PREEMPT;BDF1Ø,PR
544Ø;DEPART;1
545Ø;PREEMPT;BDF11,PR
546Ø;TRANSFER;,ADD36
547Ø*
548Ø*HIGHER ALTITUDE
549Ø*
55ØØADD85;GATE NU;HIGH1,ADD1Ø5
551ØTWO;MACRO;HIGH1
552ØTWO;MACRO;HIGH2
553ØTWO;MACRO;HIGH3
554Ø;TEST E;PL4,22Ø,ADD87
555ØTHREE;MACRO;HIGH4,HIGH1
556ØTHREE;MACRO;HIGH4A,HIGH2
557ØTHREE;MACRO;HIGH4B,HIGH3
558ØTHREE;MACRO;HIGH4C,HIGH4
559ØTHREE;MACRO;HIGH5,HIGH4A
56ØØTHREE;MACRO;HIGH6,HIGH4B
561ØADD88;ENTER;1Ø
562ØFOUR;MACRO;BDF7,HIGH4C
563ØFOUR;MACRO;BDF8,HIGH5
564ØFOUR;MACRO;BDF9,HIGH6
565Ø;TRANSFER;,ADD29
566Ø*
567ØADD87;RETURN;HIGH1
568ØTHREE;MACRO;HIGH4,HIGH2
569ØTHREE;MACRO;HIGH4A,HIGH3
57ØØTHREE;MACRO;HIGH4B,HIGH4
571ØTHREE;MACRO;HIGH4C,HIGH4A
572ØTHREE;MACRO;HIGH5,HIGH4B
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5730THREE;MACRO;HIGH6,HIGH4C
5740ADD89;ENTER;10
5750FOUR;MACRO;BDF7,HIGH5
5760FOUR;MACRO;BDF8,HIGH6
5770;PREEMPT;BDF9,PR
5780;ADVANCE;PL15
5790;TRANSFER;,ADD34
5800*
5810*NEXT HIGHER ALTITUDE
5820*
5830ADD105;GATE NU;NEXT1,ADD115
5840TWO;MACRO;NEXT1
5850TWO;MACRO;NEXT2
5860TWO;MACRO;NEXT3
5870;TEST E;PL4,220,ADD107
5880THREE;MACRO;NEXT4,NEXT1
5890THREE;MACRO;NEXT5,NEXT2
5900THREE;MACRO;NEXT6,NEXT3
5910ADD108;NULL
5920THREE;MACRO;HIGH4C,NEXT4
5930THREE;MACRO;HIGH5,NEXT5
5940THREE;MACRO;HIGH6,NEXT6
5950;TRANSFER;,ADD88
5960*
5970ADD107;RETURN;NEXT1
5980THREE;MACRO;NEXT4,NEXT2
5990THREE;MACRO;NEXT5,NEXT3
6000ADD109;NULL
6010THREE;MACRO;NEXT6,NEXT4
6020THREE;MACRO;HIGH4C,NEXT5
6030THREE;MACRO;HIGH5,NEXT6
6040THREE;MACRO;HIGH6,HIGH4C
6050;TRANSFER;,ADD89
6060*
6070*LAST ALTITUDE
6080*
6090ADD115;NULL
6100TWO;MACRO;LAST1
6110TWO;MACRO;LAST2
6120TWO;MACRO;LAST3
6130;TEST E;PL4,220,ADD117
6140THREE;MACRO;NEXT4,LAST1
6150THREE;MACRO;NEXT5,LAST2
6160THREE;MACRO;NEXT6,LAST3
6170;TRANSFER;,ADD108
6180*
6190ADD117;RETURN;LAST1
6200THREE;MACRO;NEXT4,LAST2
6210THREE;MACRO;NEXT5,LAST3
6220;TRANSFER;,ADD109
6230;LIST
6240;START;1000
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6250;RESET
6260;INITIAL;MF10(1-12,1-8),0
6270;INITIAL;MH2-MH9(1-5,1-11),0
6280;START;4000,,,1
6290;END
6300$:ENDJOB
```

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